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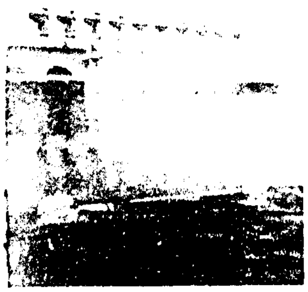

MISCELLANEOUS PAPER EL-91-15

PRELIMINARY RESULTS OF THE RICHARD B. RUSSELL FISH ENTRAINMENT STUDY

Proceedings of a Workshop

Compiled by

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This report documents technical presentations made during a workshop on the Richard B. Russell Fish Entrainment Study at Hickory Knob State Park, SC, May 1987. The workshop presentations cover data collected from February 1986 through February 1987. The study was scheduled to end in September 1988. The presentations were made to provide information on the potential for fish entrainment and consequent turbine mortality associated with pumped storage operation at Richard B. Russell Dam, Georgia-South Carolina. The following task areas of the Fish Entrainment Study are documented in the proceedings: gill net sampling, electrofishing, ichthyoplankton surveys, cove rotenone samples, near and far field hydraulic modeling, and hydroacoustic surveys.

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PREFACE

These proceedings document technical presentations made during a workshop on the Richard B. Russell Fish Entrainment Study at Hickory Knob State Park, S. C., May 1987. The workshop presented preliminary data collected and analyzed from the study from February 1986 through February 1987. The study was sponsored by the US Army Engineer District, Savannah (SAS), under Intra-Army Reimbursable Services Order No. EN-BC 86-27, dated 27 January 1986, and managed by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The workshop was organized jointly by the SAS and the WES. The workshop proceedings were compiled by Dr. John M. Nestler of the Water Quality Modeling Group (WQMG), Ecosystem Research and Simulation Division (ERSD), EL, WES. The proceedings were prepared under the direct supervision of Mr. Mark S. Dortch, Chief, WQMG, and under the general supervision of Mr. Donald L. Robey, Chief, ERSD, and Dr. John Harrison, Chief, EL. Technical reviews by Drs. C. H. Pennington and Douglas G. Clarke are gratefully acknowledged.

COL Dwayne G. Lee, CE, was the Commander and Director of WES. COL Larry B. Fulton, EN, is the present Commander and Director. Dr. Robert W. Whalin is the Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

PRELIMINARY RESULTS OF THE RICHARD B. RUSSELL FISH ENTRAINMENT STUDY
PROCEEDINGS OF A WORKSHOP

FOREWORD

Introduction

This report documents the results of a workshop held in May 1987 at Hickory Knob State Park, S. C. In this workshop, the preliminary results of the Richard B. Russell (RBR) Fish Entrainment Study were presented to representatives of the US Army Engineer District, Savannah (SAS), US Fish and Wildlife Service (FWS), Georgia Department of Natural Resources, South Carolina Wildlife and Marine Resources Department, US Army Corps of Engineers South Atlantic Division, and the FWS Atlanta Regional Office.

A workshop format was employed to transfer data and results from the Fish Entrainment Study both to decision makers within the SAS and to the other workshop participants for four reasons. First, a workshop allowed the most timely presentation of study results since the lengthy report preparation process was avoided. Thus, the information could be made available in a time frame consistent with the requirements of the power-on-line schedule. Timeliness was critical since the first decision point regarding pumped-storage operation at RBR occurred shortly after the conclusion of the workshop. At that point, the SAS had to decide whether or not to begin design work on a structural fish protection measure. Design work on a structure had to begin shortly after May 1987 for installation of the structure to be completed by 1990 coincident with power-on-line. Second, the shortened

preparation time required for a workshop allowed more recent data to be analyzed and presented. Third, the workshop format provided an opportunity for the workshop participants to directly query the technical staff who collected and analyzed the data. Technical questions could be resolved at the workshop by scientists and technicians involved in the study. Fourth, and perhaps most importantly, the workshop served as a forum for representatives of the resource agencies to discuss their impressions and interpretations of the data and to pass their recommendations regarding pumped storage at RBR directly to the decision makers of SAS.

The data presented cover the time period from February 1986 through February 1987. This report presents results for the following six task areas for which data are presently available: gillnet sampling, electrofishing, hydroacoustics, ichthyoplankton surveys, cove rotenone surveys, and hydraulic modeling. Other presentations were made during the workshop to provide supplementary or background information. These presentations were not part of the RBR Fish Entrainment Study and, consequently, are not presented in the proceedings. The most notable of these presentations was made by Mr. Joe Carroll of the US Army Engineer Waterways Experiment Station (WES) on "Water Quality Patterns Within Clarks Hill Lake." The information presented by Mr. Carroll is published in a series of annual reports documenting the activities of the RBR Limnological Laboratory. Copies of the annual reports are available from the SAS.

With the exception of the presentations by Mr. Mike Schneider and Dr. Steve Schreiner both of the WES, the presentations are of a general nature and concentrate primarily on the spatial and temporal distribution of fishes in Clarks Hill Lake as indicated by different gear types. Detailed analyses,

identifications of causality, integration of results across gear types, and presentation of convincing conclusions generally fell outside the preliminary nature of the data presented at the workshop. More complete analyses will be presented at a future workshop, as yet unscheduled, to be held at the conclusion of the Fish Entrainment Study.

The summary session presented at the conclusion of the workshop is not included in the proceedings. The resource agencies wished to formally present their written agency interpretations and recommendations to the SAS at a later date. Consequently, it would be inappropriate to preempt their formal response by including their comments and recommendations in the workshop proceedings.

Background

The SAS develops and manages water resources on the Savannah River by constructing and operating reservoir projects. RBR Dam and Lake, begun in 1976, is the most recent of the Savannah River impoundments. The RBR project is located on the Savannah River between Hartwell Lake to the northwest and Clarks Hill Lake (CHL) to the southeast and forms part of the boundary of the States of Georgia and South Carolina.

Completion of the generating facilities at RBR will significantly add to the generating capacity of the Savannah River system. Presently, hydroelectric power is generated by four 75-MW conventional hydroelectric units. Current plans provide for four additional pump-turbine units that will generate power during peak load periods.

Experience at other hydropower projects, both conventional and pumped-storage projects, in which an upstream project discharges into the headwaters of a downstream reservoir, indicates that the major effects of operation are experienced by the downstream reservoir. Pumped-storage operation, in particular, is documented to result in potentially severe mortality rates of fishes. The mortality is primarily related to the differential distribution and abundance of fishes between the forebay and afterbay. During generation, water is released from deep in the upstream reservoir where the density of fishes is generally low. Therefore, turbine mortality during generation is generally negligible at large, hydropower storage projects. However, during pumped-storage operation, water is pumped back from a shallow and narrow part of the downstream reservoir where the concentration of fishes can, at times, be high. This problem is most pronounced in tandem projects when blockage of spawning migrations by the upstream project may cause high, spring-time concentrations of fishes in the vicinity of the powerhouse. Currently, sufficient data are not available to assess the potential for turbine mortality of CHL fishes during pumpback at RBR.

CHL, the reservoir immediately downstream of RBR, has an established sport fishery that is monitored and managed (which includes annual stocking) by the States of Georgia and South Carolina. A partial list of species important to the CHL fishery includes striped bass, white bass, crappie, several species of sunfish, sauger, white catfish, channel catfish, bullhead, hybrid bass, largemouth bass, yellow perch, gizzard shad, blueback herring, threadfin shad, walleye, and flathead catfish. The States of Georgia and South Carolina, the FWS, and the SAS have all expressed their concern that turbine mortality of entrained fishes during pumpback at RBR may have a

potential impact on the CHL fishery.

RBR Fish Entrainment Study

The problem of turbine mortality could directly affect the timely completion of pumped-storage capability at RBR. Recent experience within the Corps of Engineers (CE) has indicated that pumped-storage operation has the potential to impact downstream fisheries. The SAS is sponsoring the RBR Fish Entrainment Study to collect information that can be used to avoid, or at least reduce, problems experienced at other sites. This study is designed to provide information to allow the SAS to make the best decisions regarding pumped-storage operation at RBR, that is, to provide data to optimize pumped-storage operation with minimal negative impact on the CHL fishery. Specifically, the objectives of the RBR Fish Entrainment Study are to:

(a) Determine the potential for turbine mortality during pumped-storage operation (identify species and numbers of fishes in jeopardy).

(b) Relate the significance of mortality to the total CHL fishery (relate the number of fishes in jeopardy to estimates of the total number of fishes in CHL).

(c) Relate the abundance and distribution of fishes in the tailwater to project operation, water quality, season, and reservoir hydrodynamics. This information can be used to assess operational criteria for minimizing detrimental effects on the CHL fishery.

Objectives (a) and (b) were stressed in the workshop since, at the time of the workshop, sufficient time and data were generally unavailable for most of the task areas to adequately address objective (c). However, sufficient

hydroacoustics data were available to partially address objective (c). The hydraulic simulations presented by Mr. Mike Schneider were performed to provide supporting information for the Fish Entrainment Study.

PRELIMINARY RESULTS FROM CLARKS HILL LAKE GILL NET SAMPLING

M. J. Van Den Avyle

Georgia Cooperative Fish and Wildlife Research Unit

Introduction

This report summarizes results from the first year of gill net sampling in CHL. Sampling was initiated in February 1986, and preliminary results are presented through February 1987. Gill net data are collected for two purposes. First, the data are used to describe the occurrence and temporal abundance of different species of fishes in the Savannah River arm of CHL. Secondly, gill net data are used to compare the occurrence and relative abundance of different fish species in the Savannah River arm of CHL with other areas of the lake having potentially similar physical habitat or water quality conditions.

Methods

Gill net sampling was conducted at 11 stations (Figure 1) in CHL. Four stations were located in the Savannah River arm, with three of these, Stations 1-3, being termed tailwater stations. Station 4 was located in the Russell Creek cove and was considered to be a tributary station in the data summary. One station was located in each of the remaining major tributaries

(Stations 5, 6, and 11) of CHL and four stations were located in the main body of CHL (Stations 7-10).

Sampling was conducted by WES personnel during February-June 1986, when two nets were set at Stations 1-4 for each sampling effort. Gillnetting is most effective for sampling species of fishes that are active and vulnerable to being entangled in the net mesh sizes used. The nets were 150-ft*-long multifilament experimental gill nets, consisting of six panels (25 ft each) of 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5-in. mesh (bar measure). These nets were set overnight once per month in February, March, and June 1986; samples were collected twice per month in April and May.

Personnel from the Georgia Cooperative Fish and Wildlife Research Unit (Coop Unit) conducted gillnet sampling from July 1986 through February 1987. Sampling effort was expanded in two ways: (a) nets were set at additional tributary stations (5, 6, and 11) and main lake stations (7, 8, 9, and 10); and (b) four nets (rather than two) were set per sample period at Stations 2-11. The sampling effort remained at two nets for Station 1. At Station 1, both nets were placed on the spillway side of the dam because currents created during generation prevented setting nets near the draft tubes. At Stations 2-11, each sample effort consisted of two nets set near the shoreline (perpendicular) and two offshore nets. Samples were collected

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

once per month at Stations 1-4 and during July, September, and December at Stations 5-11.

Results and Discussion

Results of the gill net sampling demonstrated considerable spatial and temporal variation in the occurrence and abundance of fishes. These trends probably resulted from two factors. First, some species were probably blocked during attempted spawning migrations up the Savannah River by the RBR dam. Second, releases from RBR dam created a zone of cool water habitat that attracted several species of fishes during summer, most notably striped bass and striped bass x white bass hybrids (referred to as hybrids in this and other presentations). Preliminary results from the gillnetting data indicate that the Savannah River arm of CHL provides an important and seasonally unique habitat area for several valuable sport fish (striped bass, hybrids, sauger, and walleye).

The gill net data must be evaluated within the context of the hydrological and meteorological conditions during the sampling period. The period from February 1986 through February 1987 included an extreme drought and heat wave and spring and summer water levels in CHL reached record lows. The effect of the unusual meteorological and hydrological conditions on catch rates is unknown and cannot be evaluated until more gill net data become available.

Spatial pattern

Gill net sampling indicated considerable differences in occurrence and species composition between different parts of CHL (Figure 2). Some caution should be exercised in interpreting Figure 2; each subfigure is based on a different sampling effort, preventing direct comparison of abundances among the subfigures. However, patterns of abundance within a subfigure can be compared with patterns in other subfigures. Samples of fishes were most diverse at the tailwater stations (1-3), where 31 species were collected, followed by 21 species at the tributary stations (4, 5, 6, and 11) and 18 species at the lake stations (7, 8, 9, and 10). Species caught in relatively high numbers in the tailwater stations included hybrids, carpsuckers, common carp striped bass, gizzard shad, silver redhorse, sauger, spotted sucker, white bass, and walleye.

Results of the gill net sampling indicated that the tailwater of RBR provided important habitat for some of the major species in CHL. Of the 11 most abundant species collected in the tailrace (Stations 1-3), 6 tended to have higher catch rates in the tailwaters than at the other tributaries or main lake stations. These species included hybrids (Figure 3), striped bass (summer only, Figure 4), carpsuckers (Figure 5), silver redhorse (Figure 6), spotted sucker (Figure 7), and sauger (Figure 8). Longnose gar catches were highest at the tributary stations, followed by the main lake, and lowest at the tailwater (Figure 9). Four species had similar catch rates at all categories of stations: common carp (Figure 10), gizzard shad (Figure 11), white bass (Figure 12), and largemouth bass (Figure 13).

Temporal trends (tailwater)

Fish species in the tailwater stations (1-3) could be broadly categorized by their temporal patterns of occurrence. Four species tended to be present throughout the year: hybrids, white bass, common carp, and gizzard shad (Figures 14, 15, 16, and 17). Striped bass catches were highest in summer and fall (Figures 14, and 15), and gar catches were highest in spring and summer (Figures 16 and 17). Hybrids and striped bass, game species that are known to require cooler summer water temperatures, were probably attracted to the vicinity of the powerhouse in the summer and early fall by the cool water released from RBR Dam. Four species were abundant in all seasons except summer: sauger, carpsucker, silver redhorse, and spotted sucker (Figures 18, 19, 20, and 21).

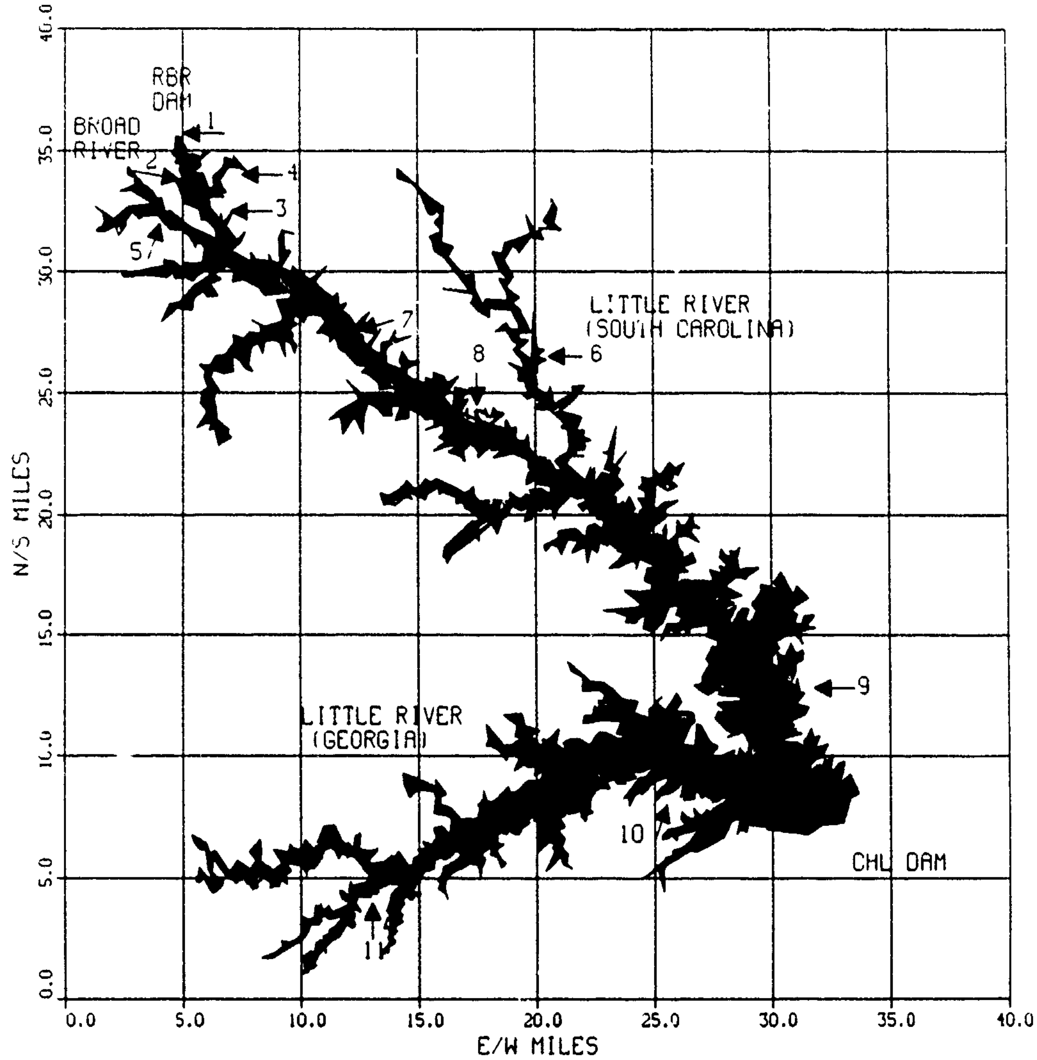


Figure 1. Gill net sampling station locations in CHL. Four stations are located in the Savannah River arm of the lake, one is located in each of the other major tributaries, and four are located in the main portion of the lake

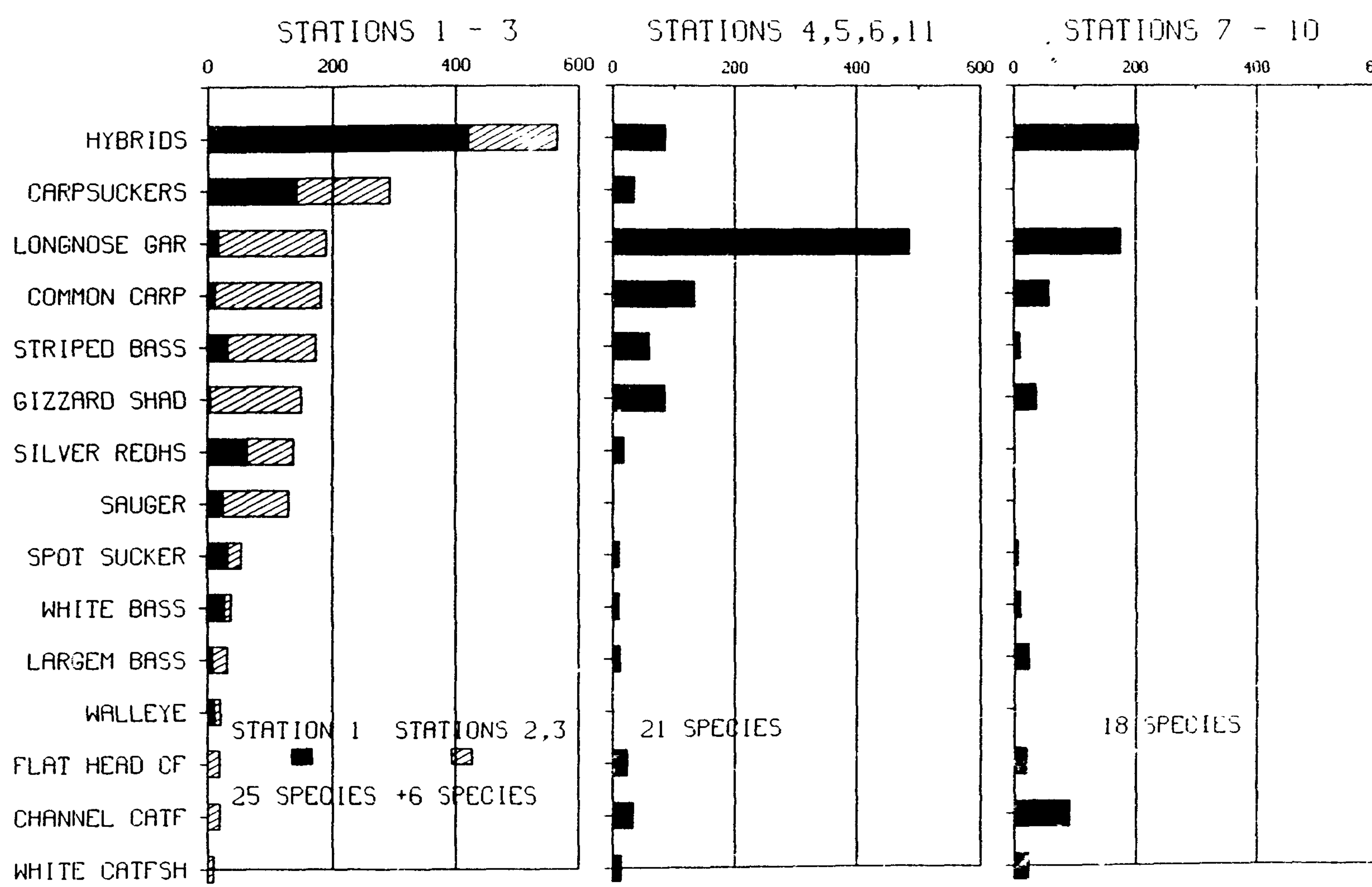


Figure 2. Gill net catch summaries (total kilograms caught), by species, in different parts of CHL. Catches in each subfigure are based on different levels of effort, preventing a direct comparison of species abundances across subfigures. However, patterns of abundance within a subfigure can be compared with patterns of abundance in other subfigures

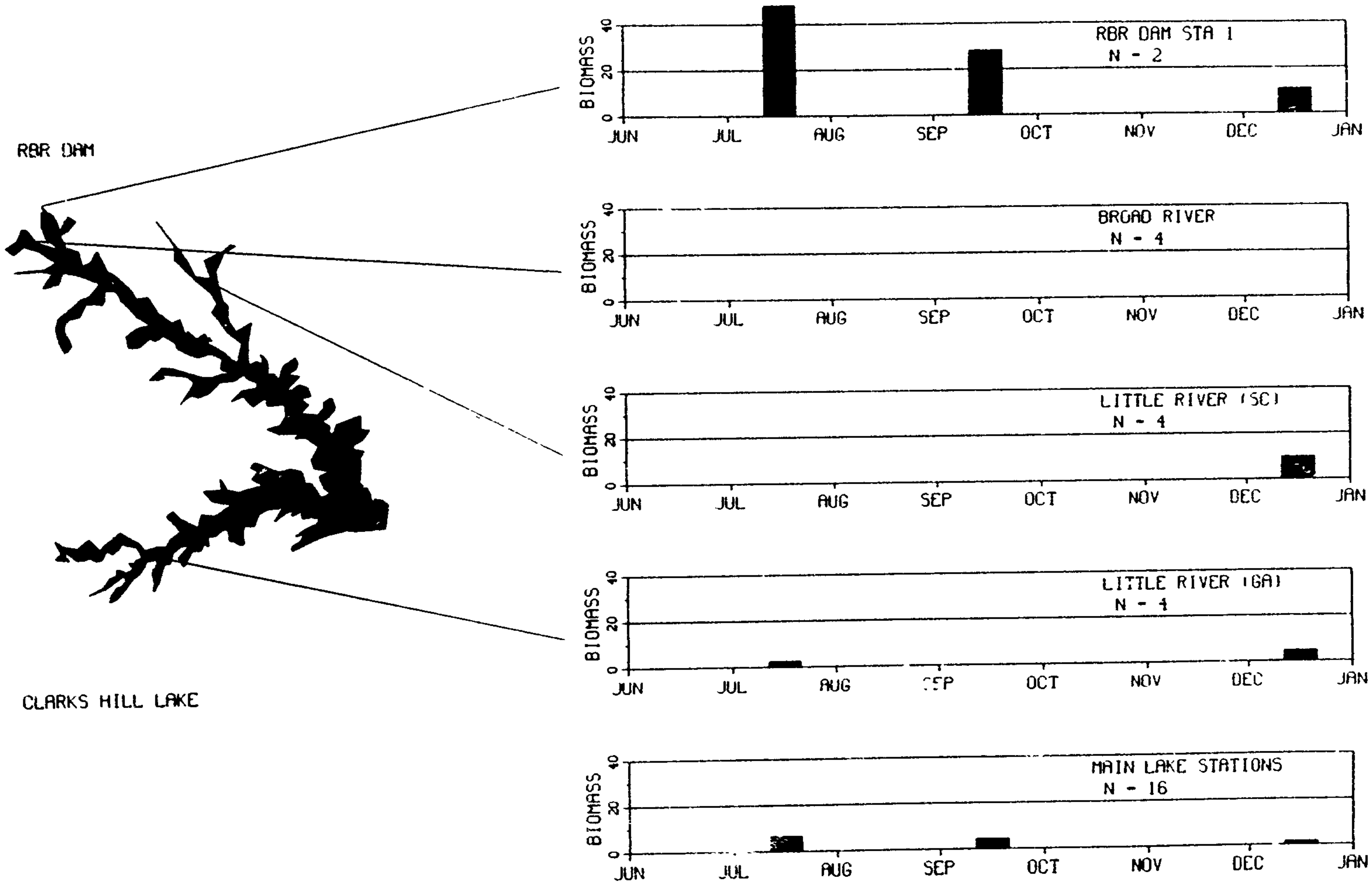


Figure 3. Spatial distribution of hybrid bass mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.-Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10). Note comparatively high catch biomasses at Station 1

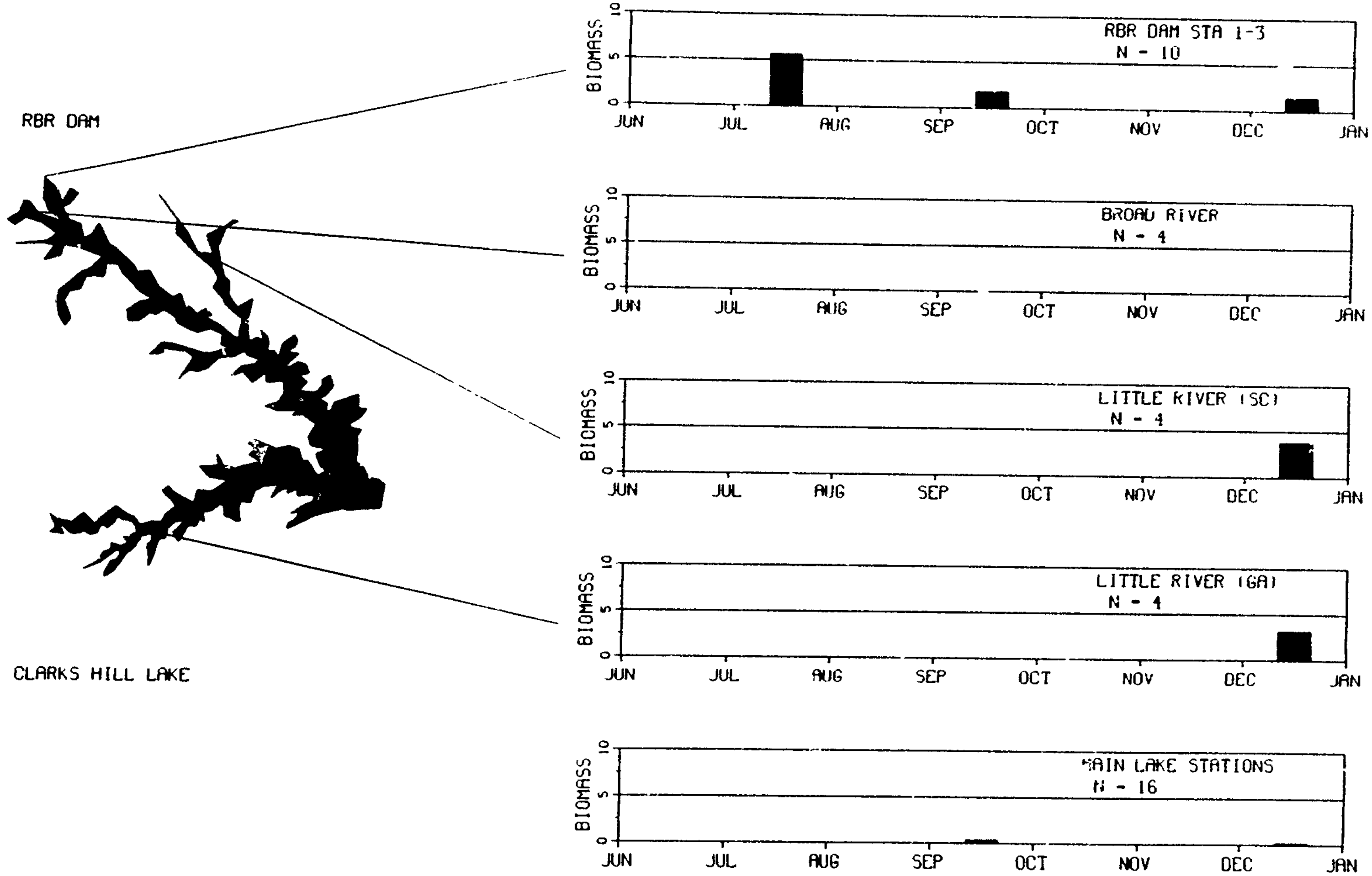


Figure 4. Spatial distribution of striped bass mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10). Note high summer and fall catch rates at Station 1

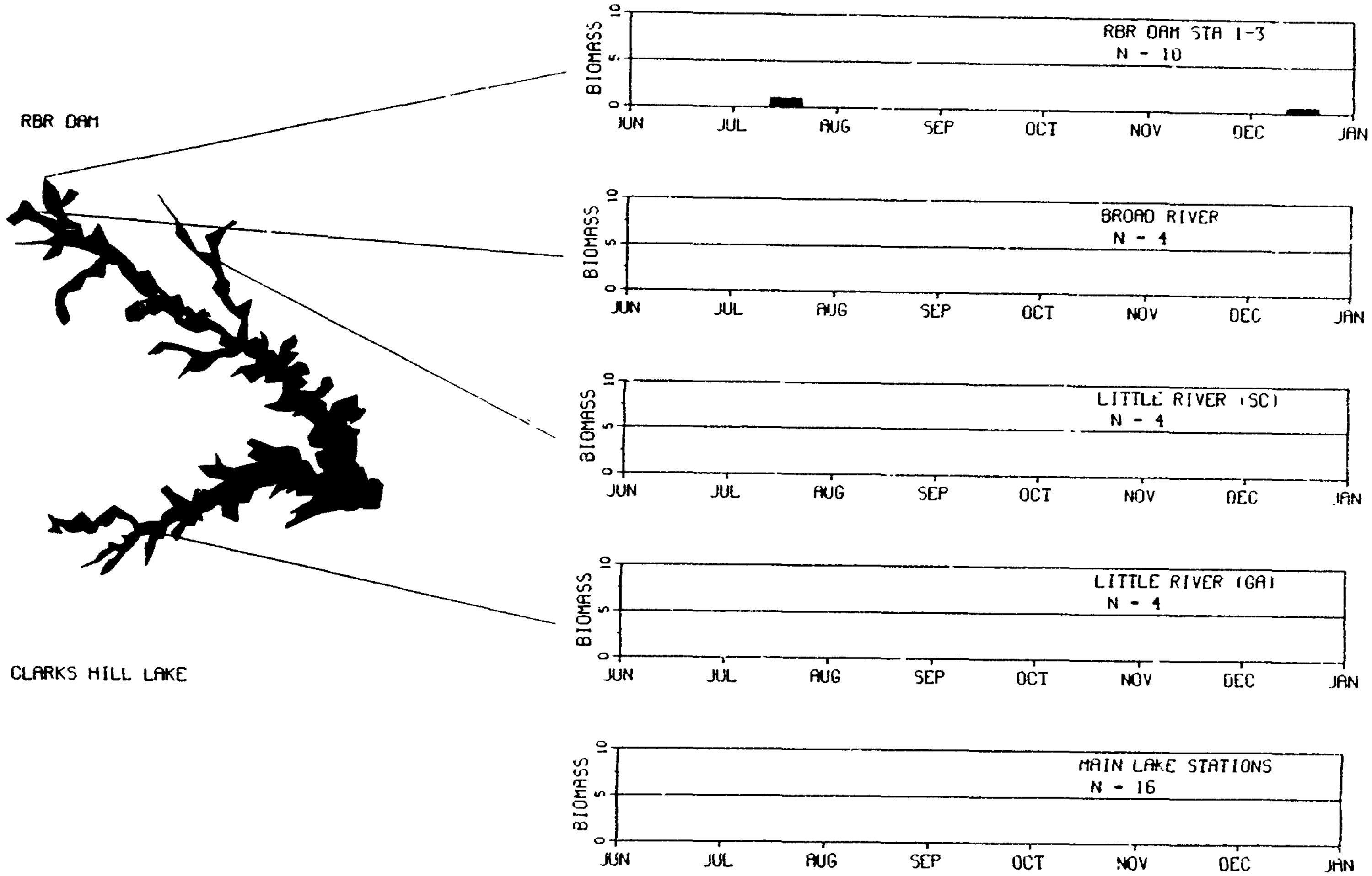


Figure 5. Spatial distribution of river and quillback carpsucker mean catch rates, combined, in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with the mean catch rates for the four main lake stations (Stations 7-10)

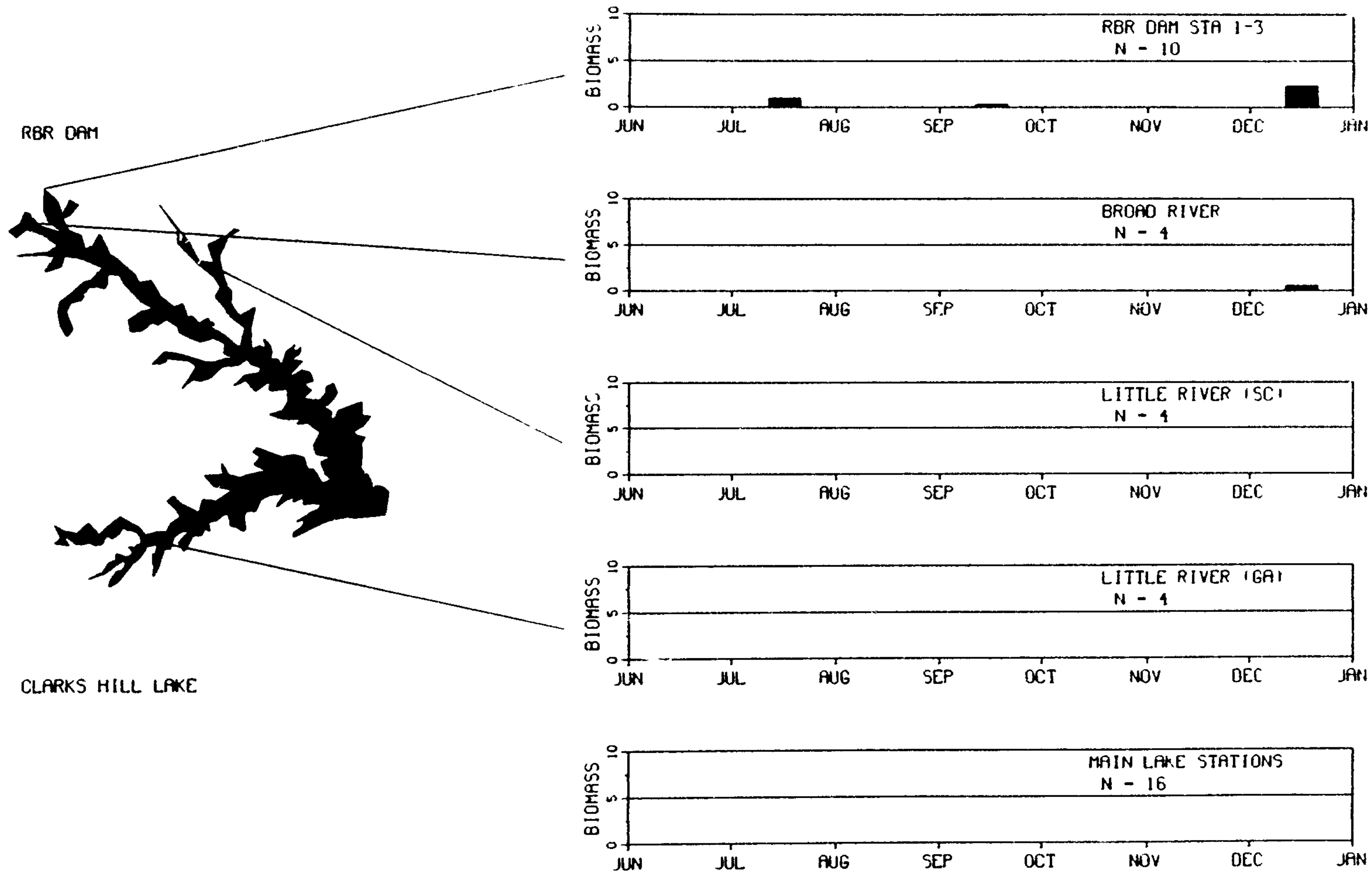


Figure 6. Spatial distribution of silver redhorse mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

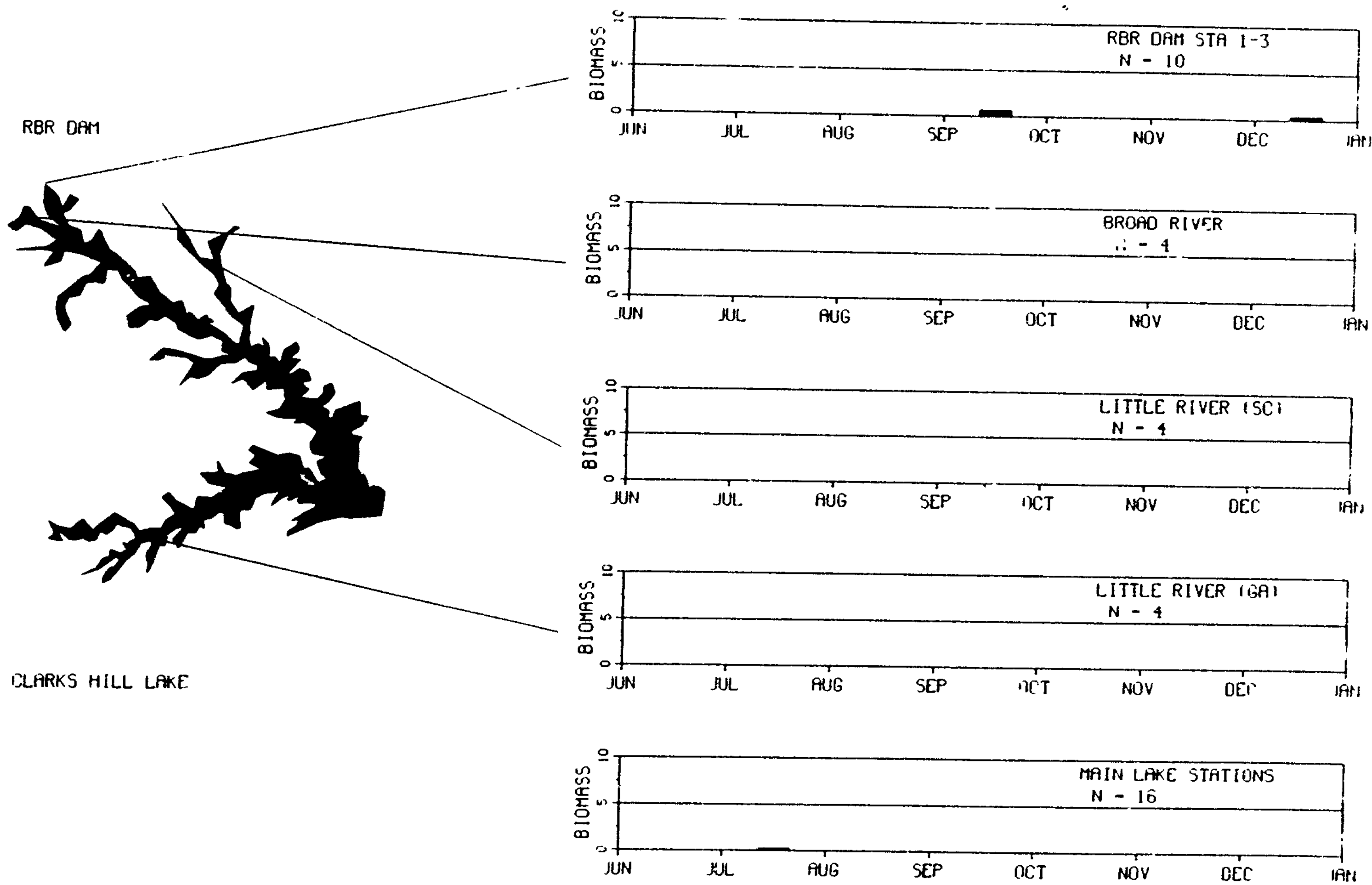


Figure 7. Spatial distribution of spotted sucker mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

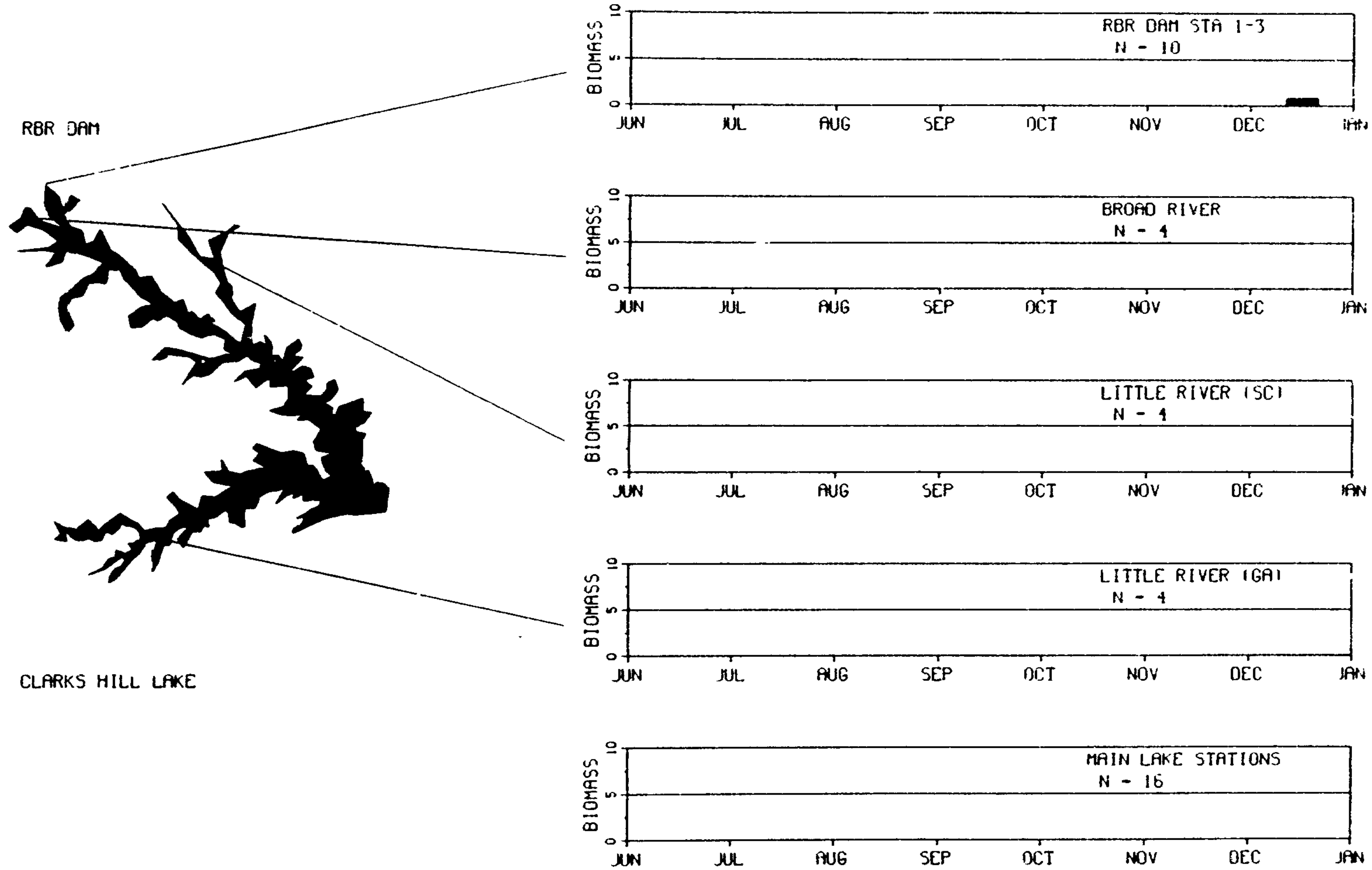


Figure 8. Spatial distribution of sauger mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

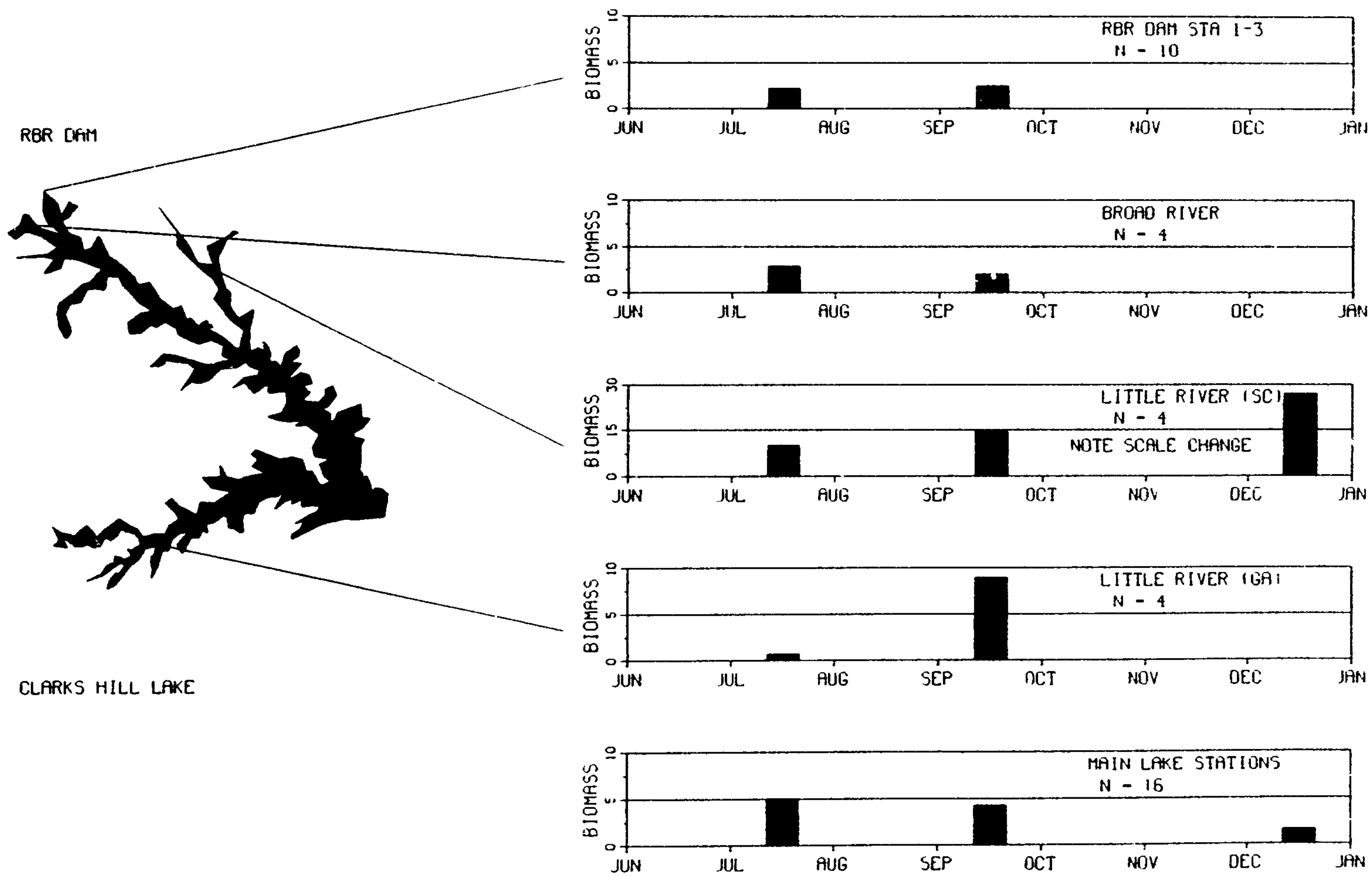


Figure 9. Spatial distribution of longnose gar mean catch rates July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

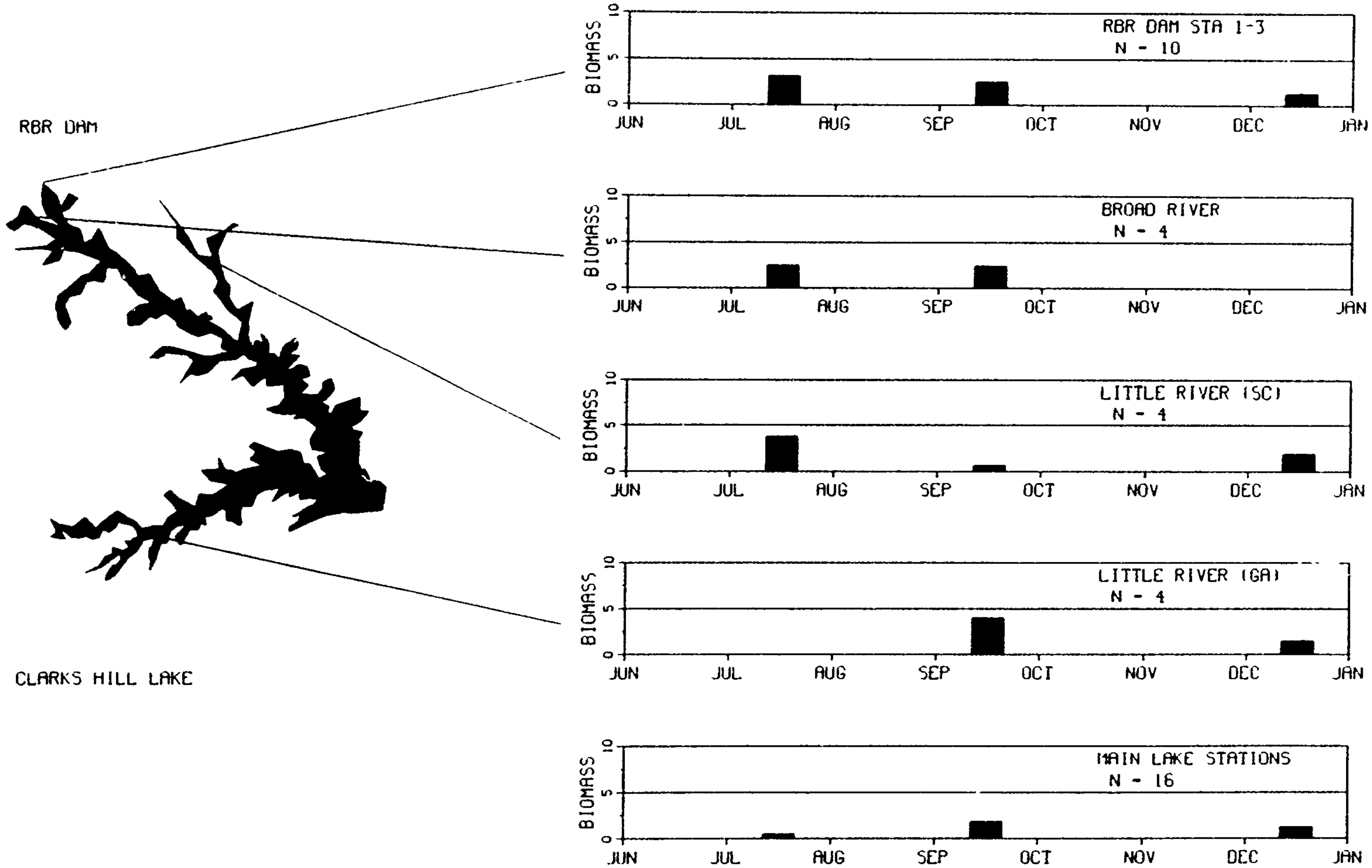


Figure 10. Spatial distribution of common carp mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

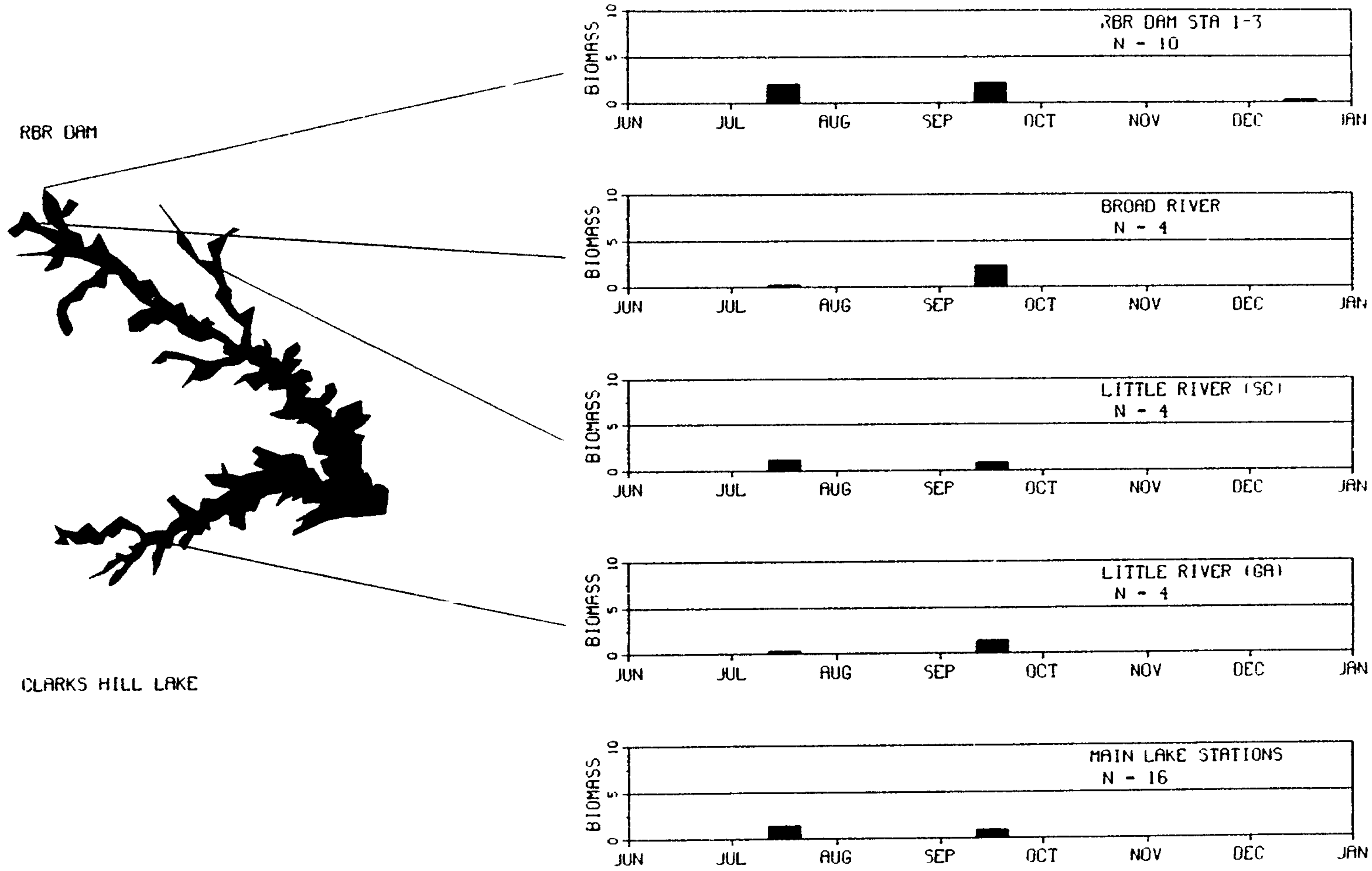


Figure 11. Spatial distribution of gizzard shad mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

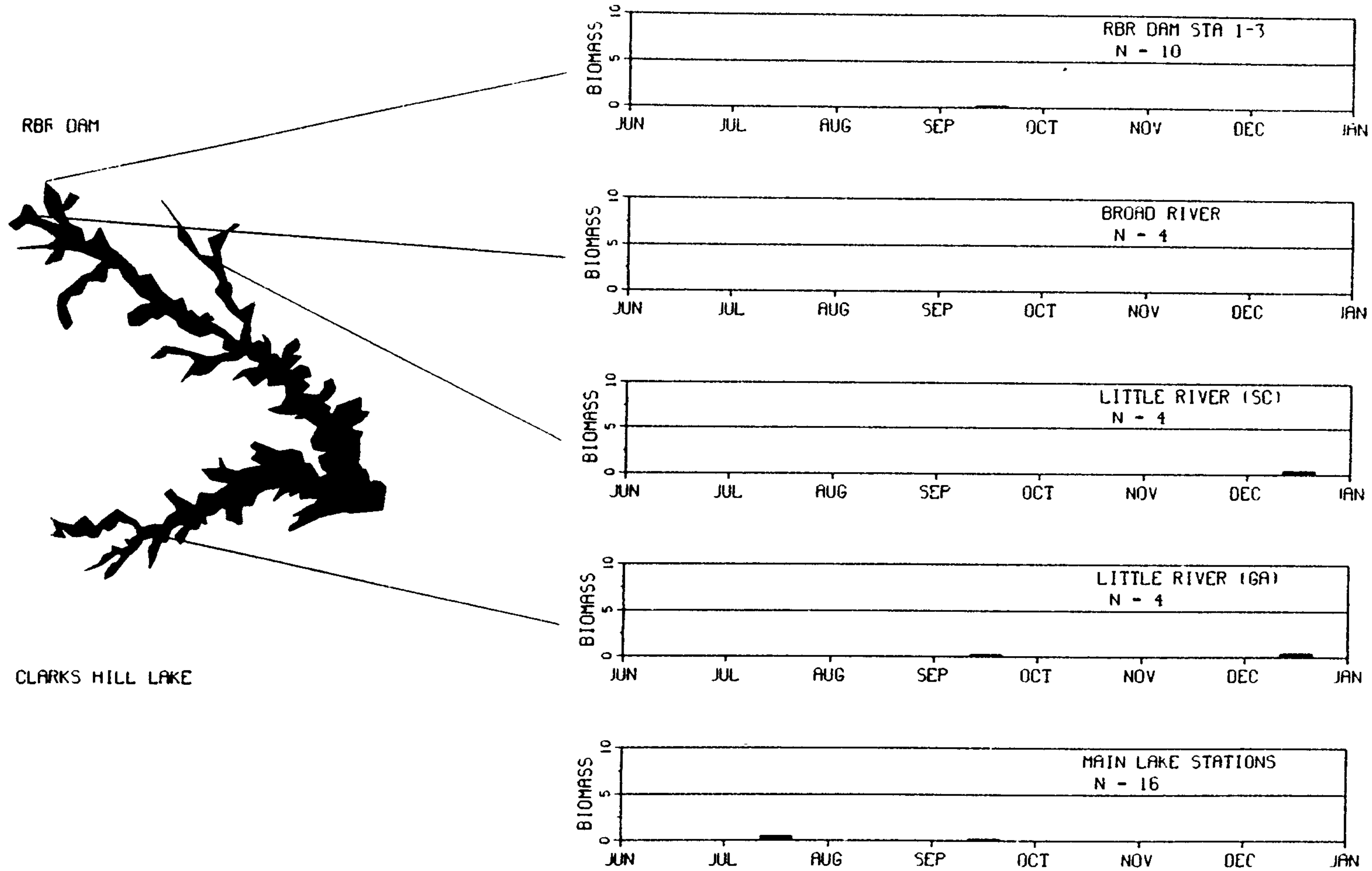


Figure 12. Spatial distribution of white bass mean catch rates in July, September, and December of 1986. Catch rates (kilograms/gill net; n = number of gill nets) at each major tributary (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

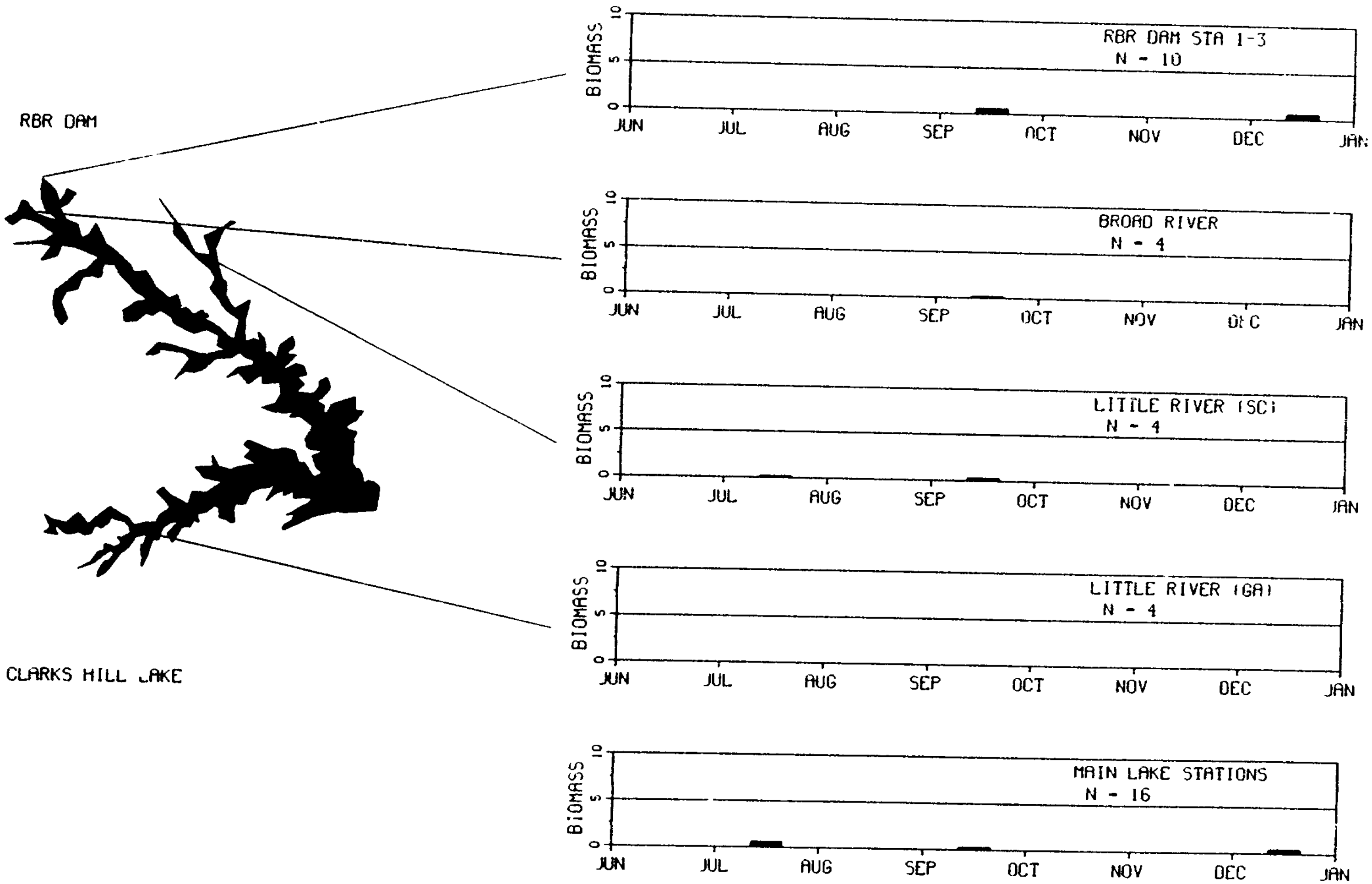


Figure 13. Spatial distribution of largemouth bass mean catch rates (kilograms/gill net: n = number of gill nets) in July, September, and December 1986. Catch rates at each major tributary (Savannah River-Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with the mean catch rates for the four main lake stations (Stations 7-10)

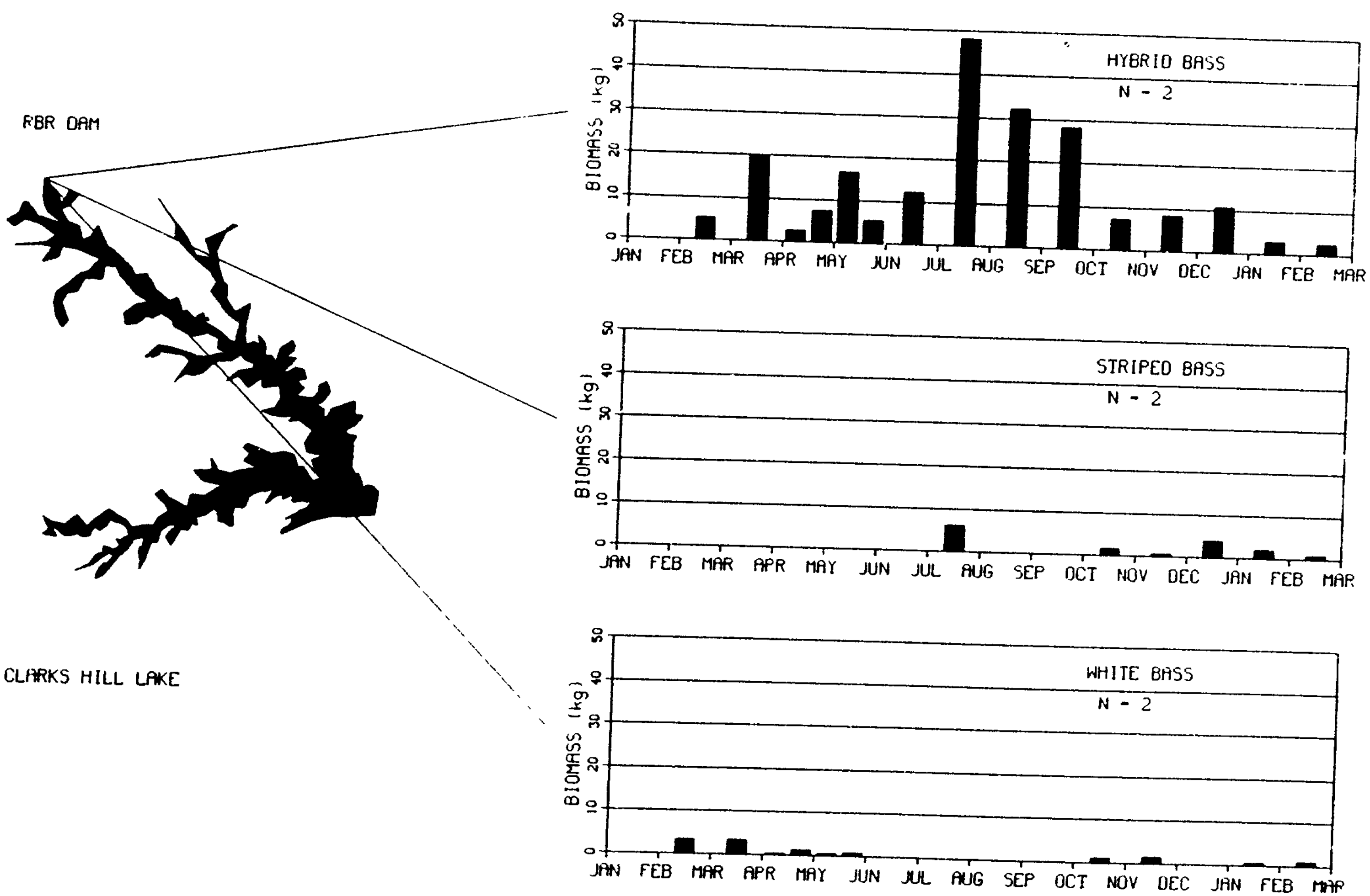


Figure 14. Temporal distribution of temperate bass mean catch rates (kilograms/gill net; n = number of gill nets) in the tailrace of RBR dam (Station 1) from February 1986-February 1987. Note both the high, year-round relative catch rates and summertime peak for hybrid bass

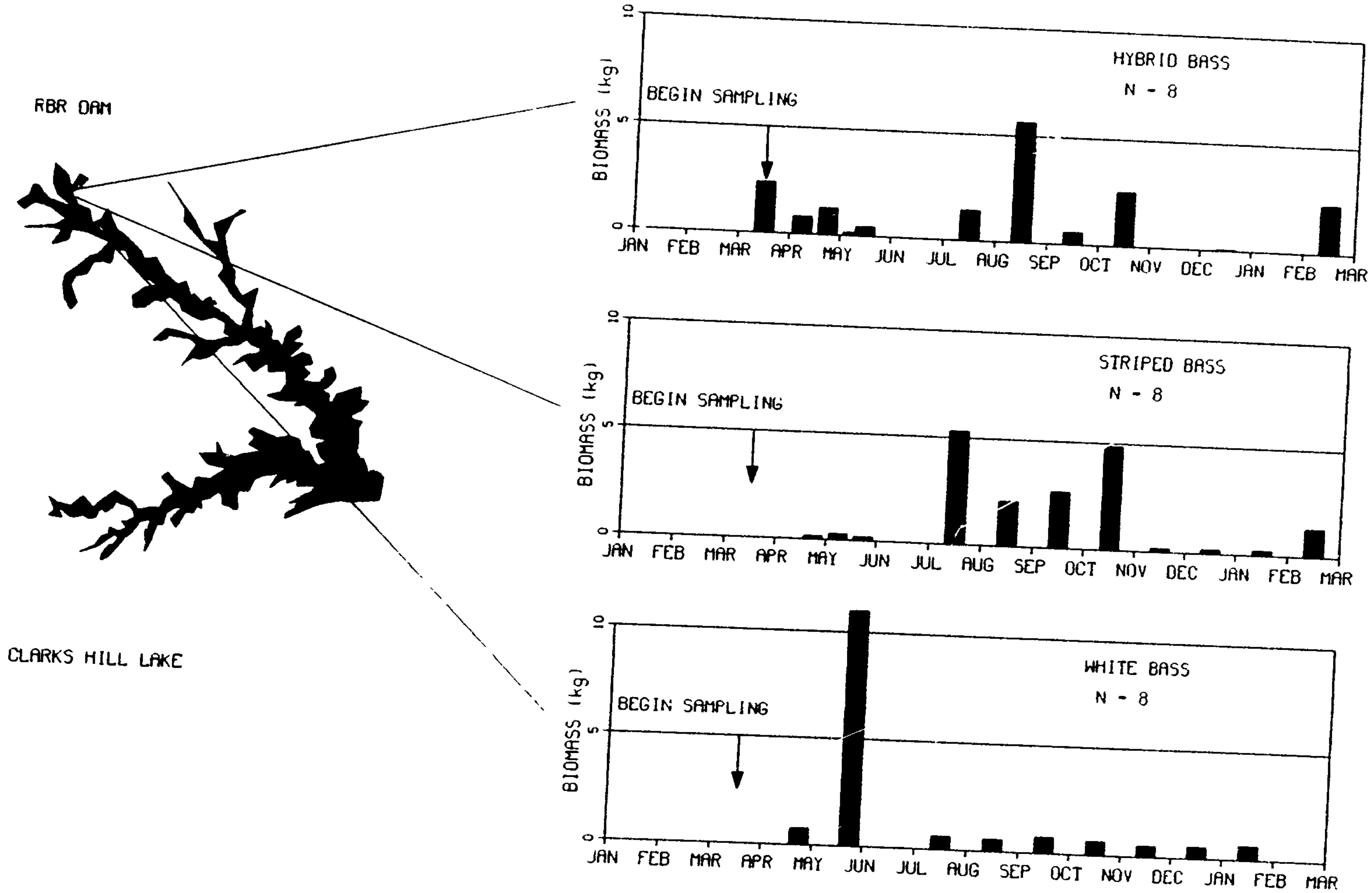


Figure 15. Temporal distribution of temperate bass mean catch rates (kilograms/gill net; n = number of gill nets) in the tailwater of RBR dam (Stations 2-3) from February 1986-February 1987. Note the high catch rates for striped bass in the fall

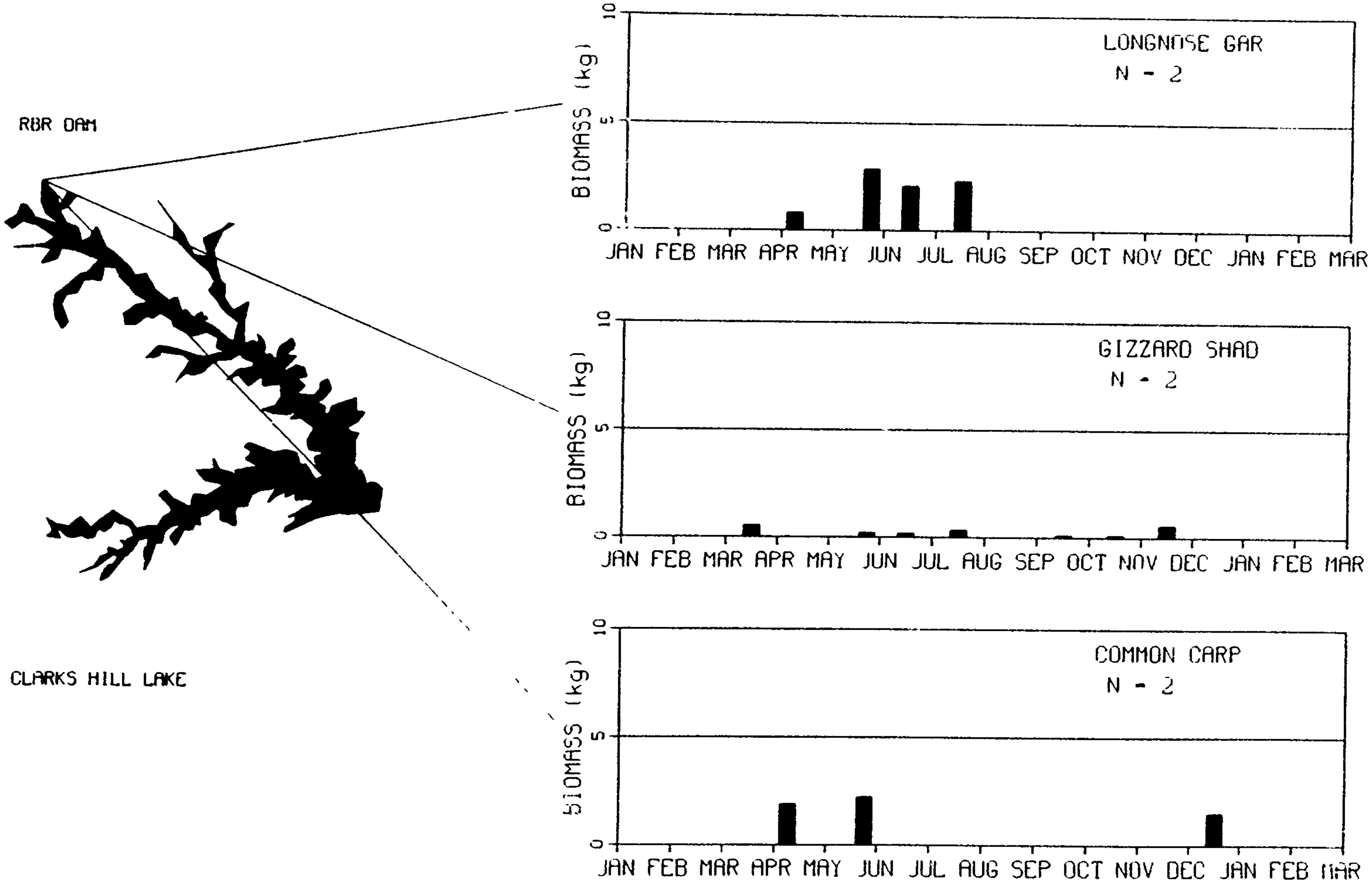


Figure 16. Temporal distribution of mean catch rates (kilograms/gill net; n = number of gill nets) for select rough fishes in the tailrace of RBR dam (Station 1) from February 1986-February 1987

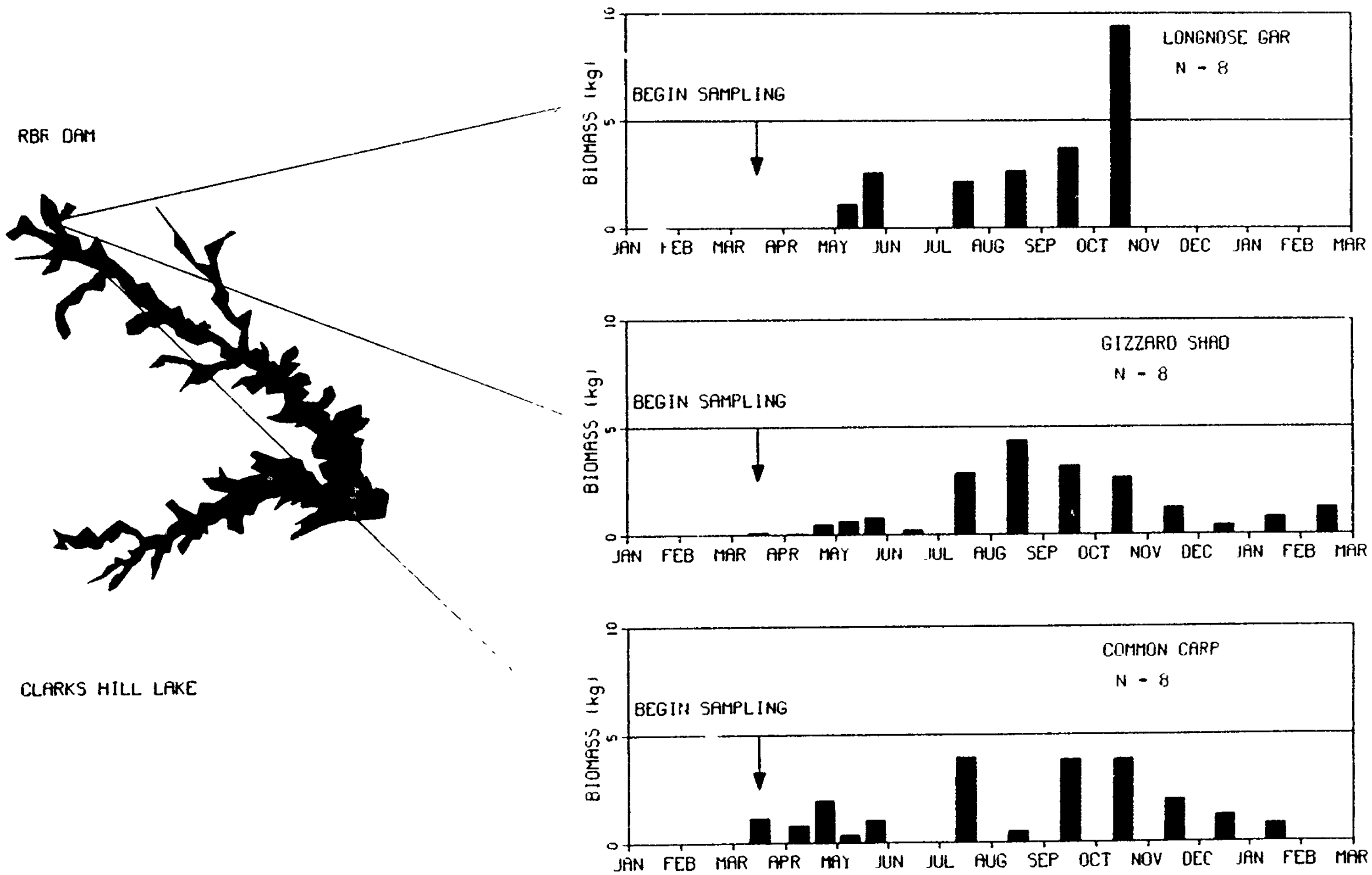


Figure 17. Temporal distribution of mean catch rates (kilograms/gill net; n = number of gill nets) for select rough fishes in the tailwater of RBR dam (Station 2-3) from February 1986-February 1987

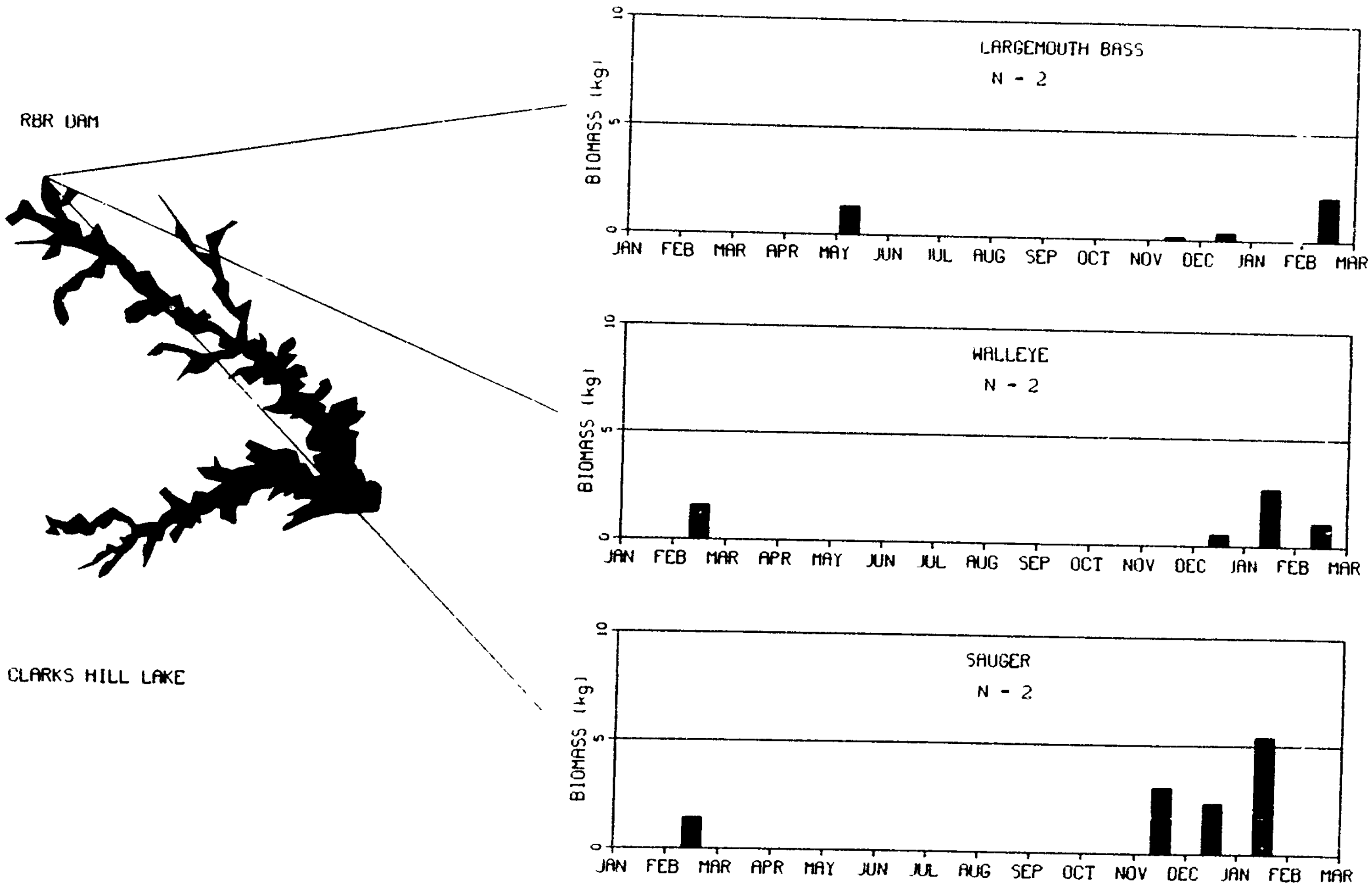


Figure 18. Temporal distribution of mean catch rates (kilograms/gill net; n = number of gill nets) of select sport fishes in the tailrace of RBR dam (Station 1) from February 1986-February 1987

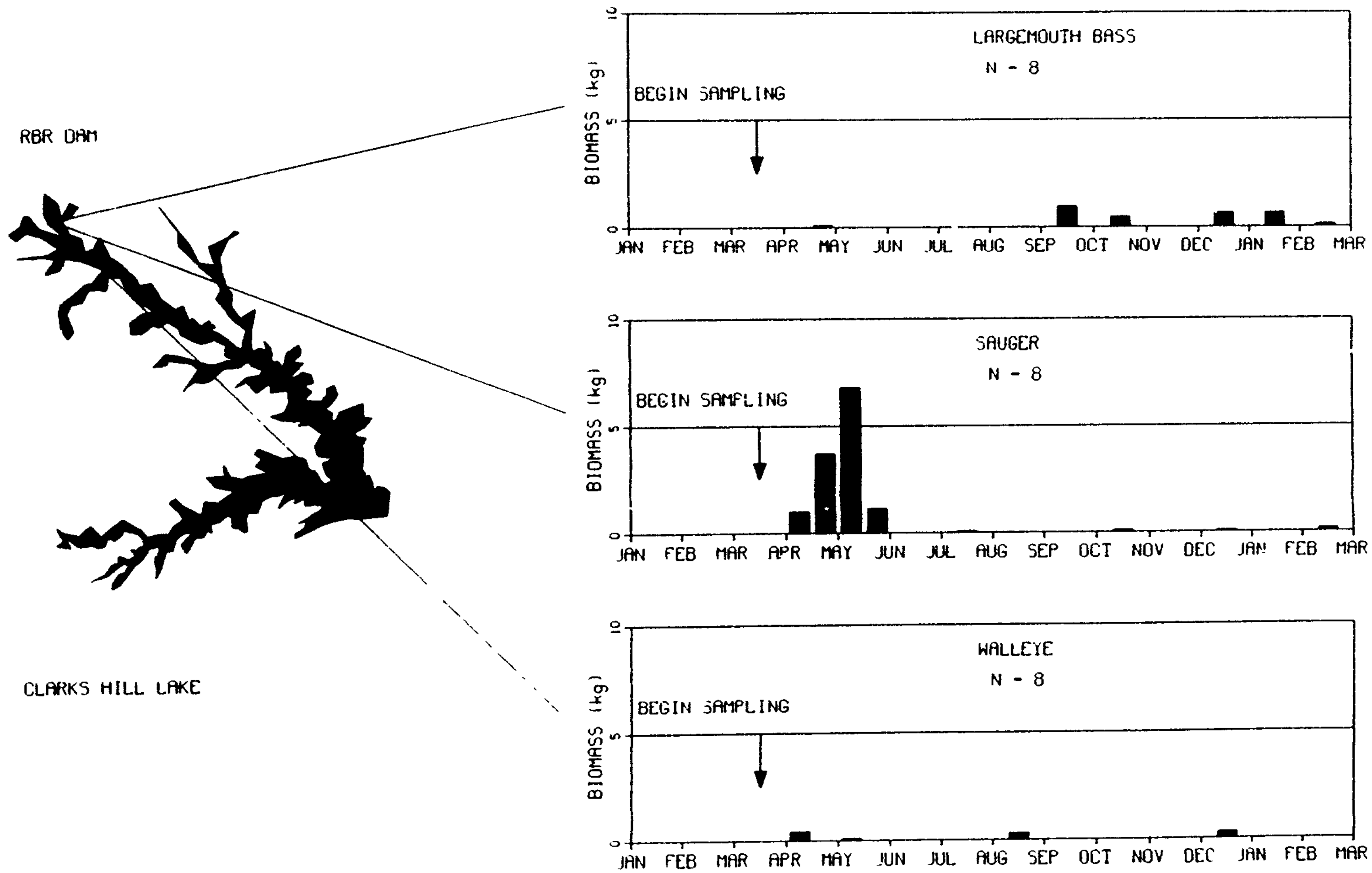


Figure 19. Temporal distribution of mean catch rates (kilograms/gill net; n = number of gill nets) of select sport fishes in the tailwater of RBR dam (Stations 2-3) from February 1986-February 1987

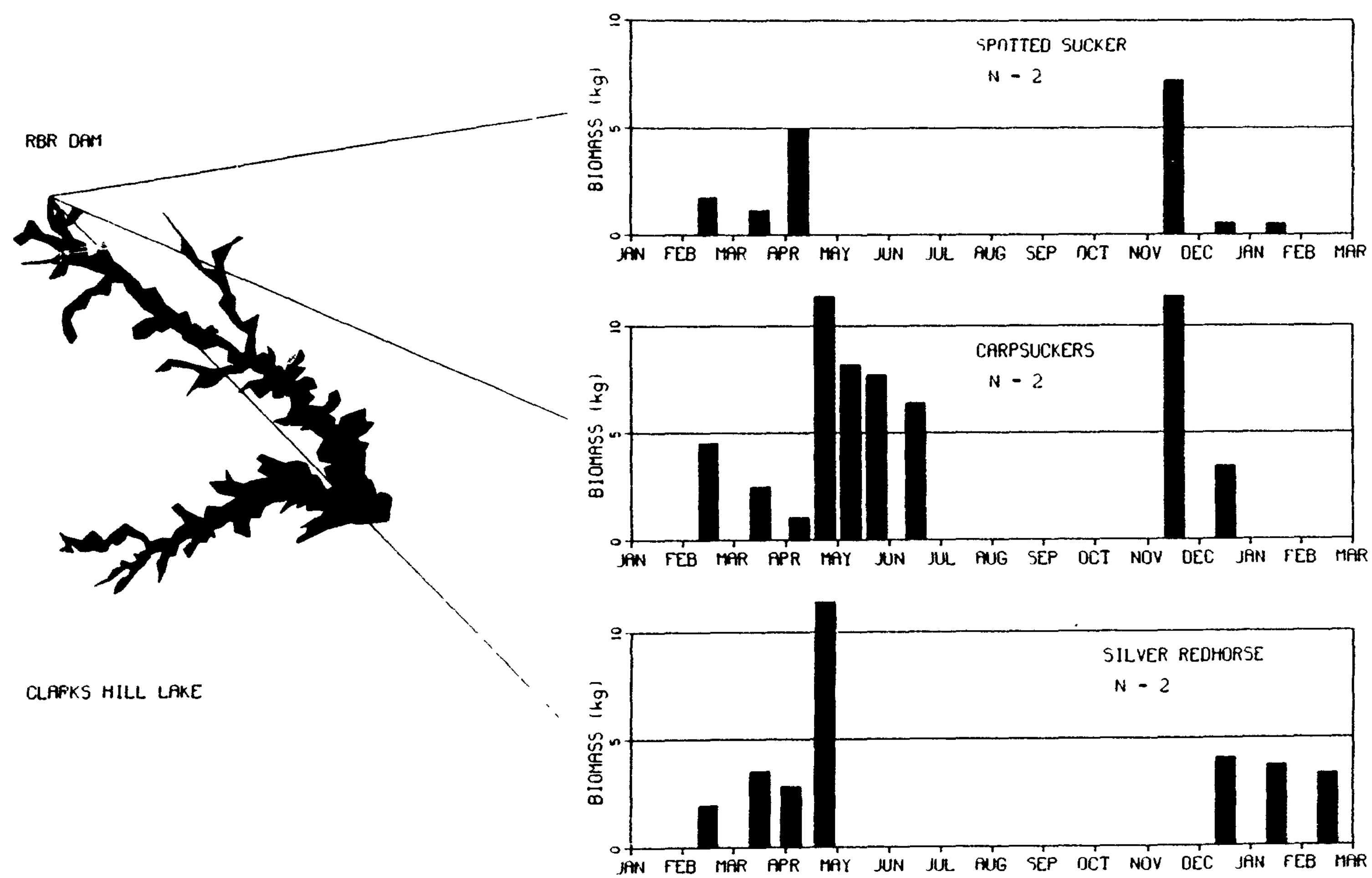


Figure 20. Temporal distribution of mean catch rates (kilograms/gill net; n = number of gill nets) for common suckers in the tailrace of RBR dam (Station 1) from February 1986-February 1987

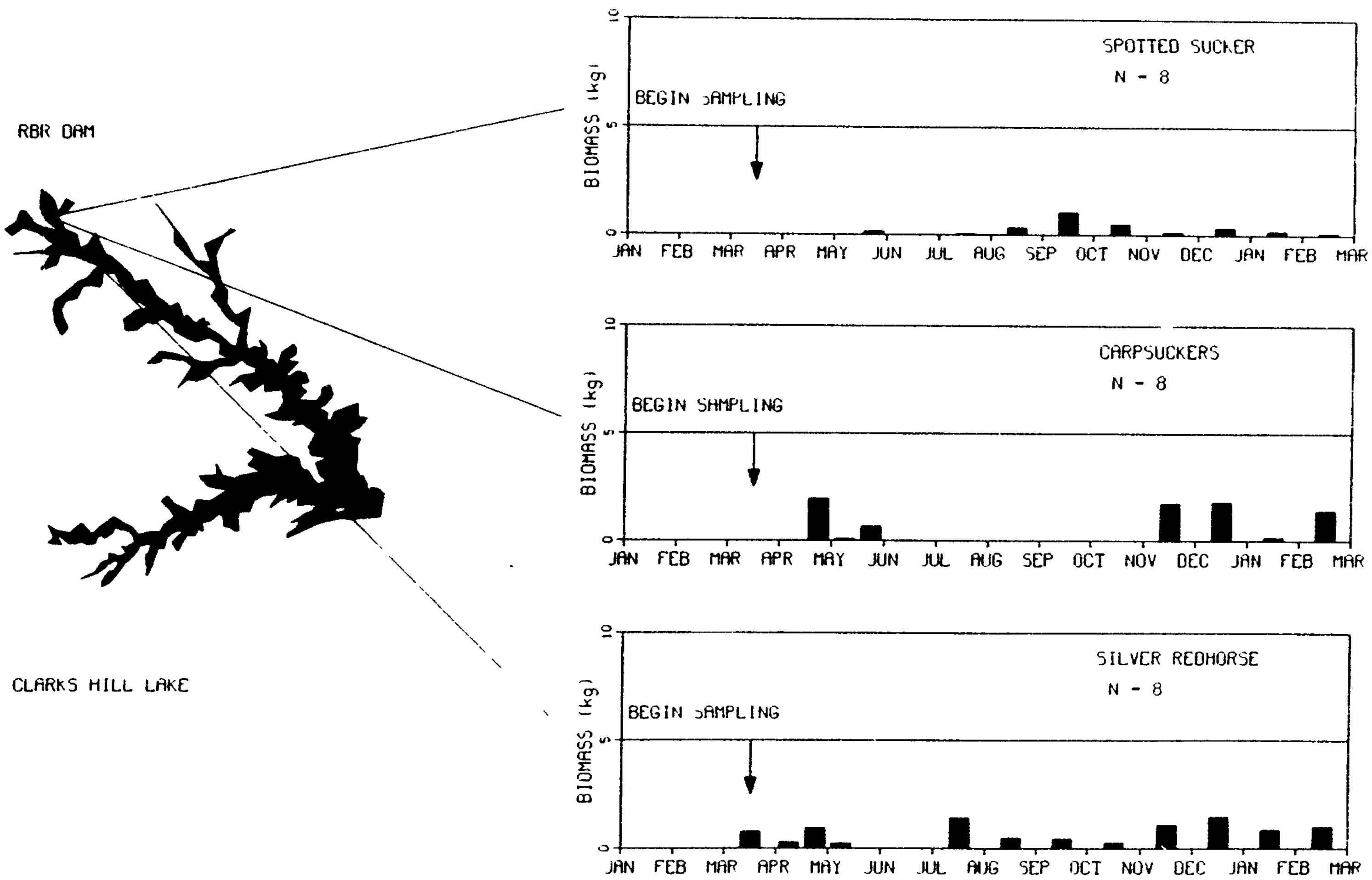


Figure 21. Temporal distribution of mean catch rates (kilograms/gill net; n = number of gill nets) for common suckers in the tailwater of RBR dam (Stations 2-3) from February 1986-February 1987

PRELIMINARY RESULTS FROM CLARKS HILL ELECTROSHOCKING SAMPLING

M. J. Van Den Avyle and T. J. Welch

Georgia Cooperative Fish and Wildlife Research Unit

Introduction

This presentation summarizes results from the first year of electrofishing sampling in CHL. Sampling was initiated in July 1986 by the Georgia Cooperative Fish and Wildlife Unit, and data are presented through February 1987. Electrofishing data were collected for two reasons. First, the data are used to describe the occurrence and relative abundance of different fishes in the Savannah River arm of CHL. Secondly, the electroshocking data are used to compare the occurrence and relative abundance of different fish species in the Savannah River arm of CHL with other areas of the lake having potentially similar physical habitat or water quality conditions.

Methods

Electrofishing was conducted at 11 stations (Figure 1) in CHL, consistent with locations used for gillnet sampling. Four stations were located in the Savannah River arm with three of these, Stations 1-3, being termed tailwater stations. Station 4 was located in the Russell Creek cove and was considered to be a minor tributary station. A single station was located in each of the

remaining major tributaries (Stations 5, 6, and 11) of CHL, and four stations were located in the main body of CHL (Stations 7-10).

Electrofishing at Stations 2-11 consisted of sampling three permanently located 500-ft transects that were randomly selected at the beginning of the study. At Station 1, however, sampling efforts were confined to three 1,000-ft transects, one along the South Carolina shoreline, one along the Georgia shoreline, and one along the dam face. In addition, Station 1 was sampled twice during each sampling period. Electrofishing was performed prior to generation (pregeneration sample) and after generation (postgeneration sample). The pregeneration sample was generally collected during daylight hours and the postgeneration sample was generally collected at night. Results are presented in catch per unit effort as mean kilograms/hour of electrofishing for each station.

Results

Samples of fishes collected by electrofishing were most diverse at the tailwater stations (1-3), where 36 species were collected, followed by the tributary stations (4, 5, 6, and 11) with 28 species, and the main lake stations (7, 8, 9, and 10) with 22 species. Largemouth bass, bluegill, and gizzard shad biomasses were relatively high at all locations (Figure 2); biomasses appeared higher at Stations 2 and 3 and in the tributaries than in the main lake. In general, the species collected and catch rates at Stations 2 and 3 of the tailrace were similar to those at the other tributaries

(Stations 4, 5, 6, and 11) and higher than those of the main lake Stations (7, 8, 9, and 10).

Within the tailwater, more species were collected at Station 1 than at any other station, and hybrid bass and striped bass were collected only at Station 1. However, caution must be exercised in interpreting Station 1 data since it differs from the others in transect length and in the presence of artificial shoreline habitats (e.g., riprap, the dam face).

Spatial trends

The spatial distributions of fishes at the different stations in CHL, as indicated by electroshocking, were generally uniform with most species being collected at most stations (Figures 3, 4, 5, 6, 7, and 8). This result is probably related to the uniformity of littoral zone habitat in CHL. Generally, the littoral zone is composed of eroded lakeshore with occasional cover provided by fallen trees. Electroshocking is the most effective gear to sample fishes in this type of habitat.

Temporal trends (tailwater)

At Station 1, hybrids were collected only in August, and striped bass were caught during September and October (Figures 9 and 10). Largemouth bass were collected throughout the sampling period and were usually more abundant in postgeneration samples (Figure 11). This was probably caused by improved sampling efficiency at night, when most postgeneration collections were made. At Stations 2 and 3, largemouth bass were also captured during the entire

sampling period but were most abundant during late summer and early fall (Figure 11).

Spotted suckers (Figure 12) were caught from July-October at Station 1 during pregeneration and from July-December during postgeneration. In addition, spotted suckers were found throughout the sampling period at Stations 2 and 3 but were most prevalent during the winter months.

Bluegills were present in catches throughout the sampling period at Stations 1, 2, and 3 (Figure 13). Also, gizzard shad (Figure 14) were caught predominantly in late summer throughout the tailwater area. Silver redhorse (Figure 15) were collected primarily at Stations 2 and 3, as were yellow perch (Figure 16) and redear sunfish (Figure 17).

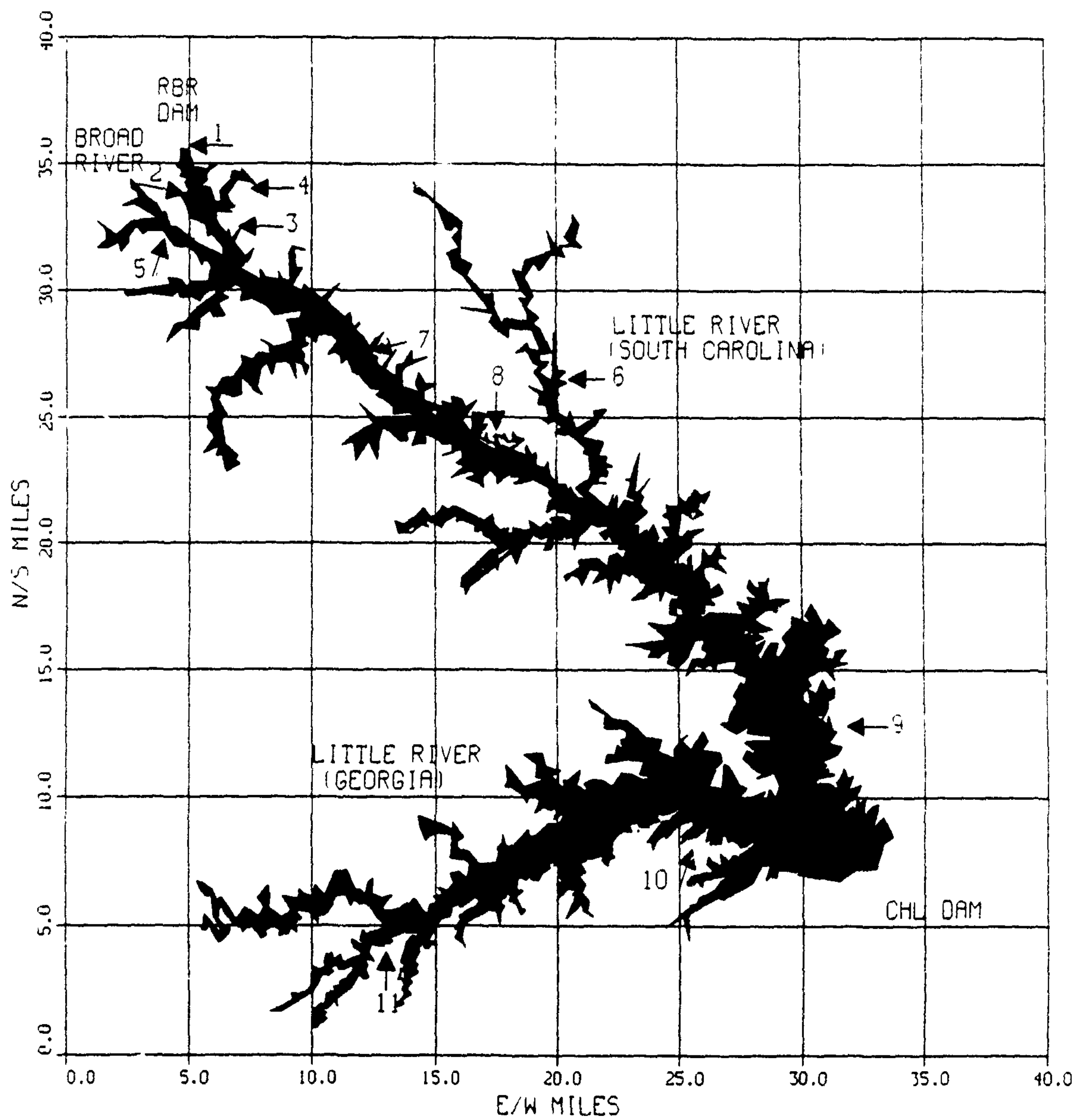


Figure 1. Electrofishing station locations in CHL. Four stations are located in the Savannah River arm of the lake, one is located in each of the other major tributaries, and four are located in the main portion of the lake

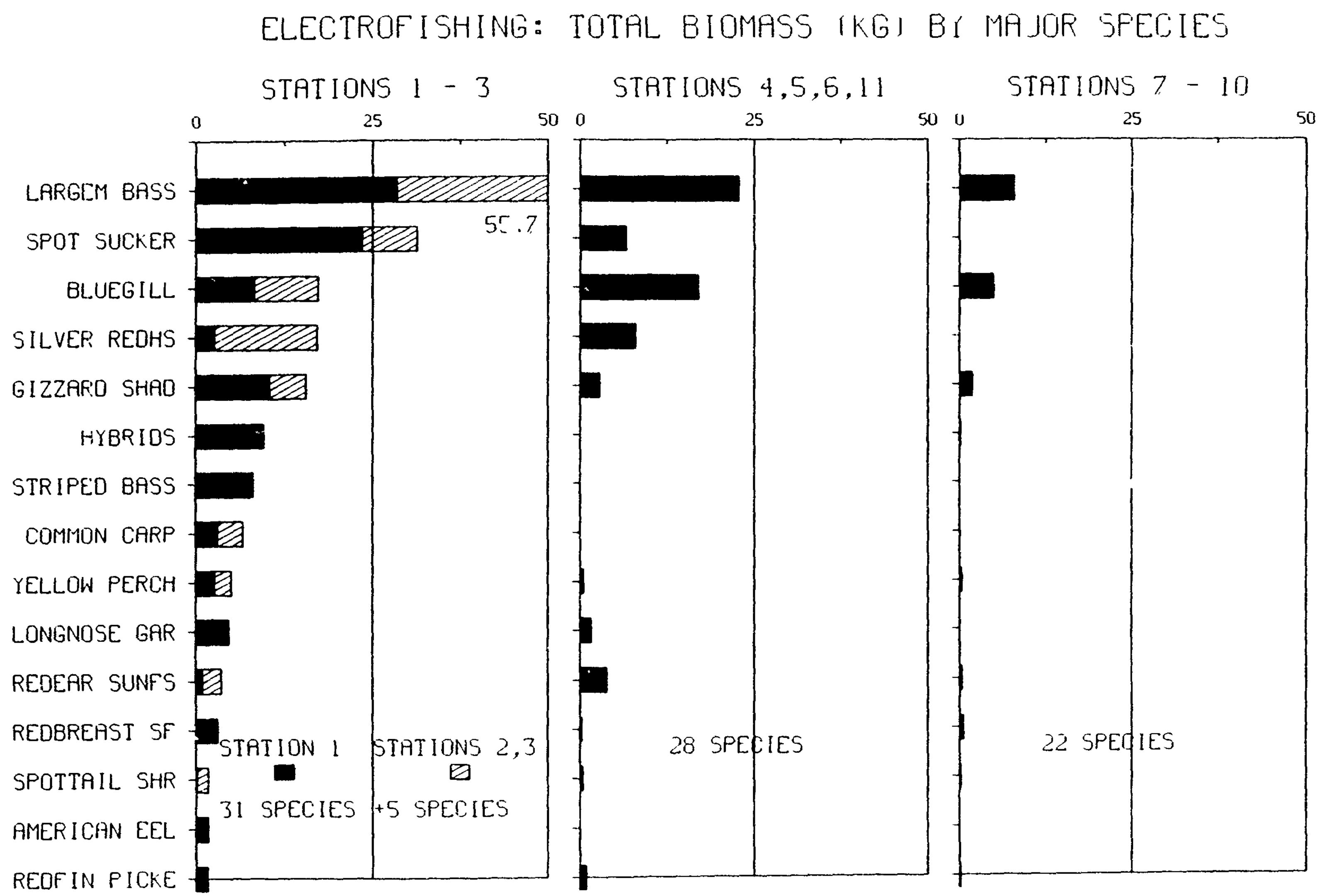


Figure 2. Electrofishing catch summaries (total kilograms), by species, in different parts of CHL. Catches in each subfigure are based on different levels of effort, preventing a direct comparison of species abundances across subfigures. However, patterns of biomass within a subfigure can be compared with patterns of biomass in other subfigures

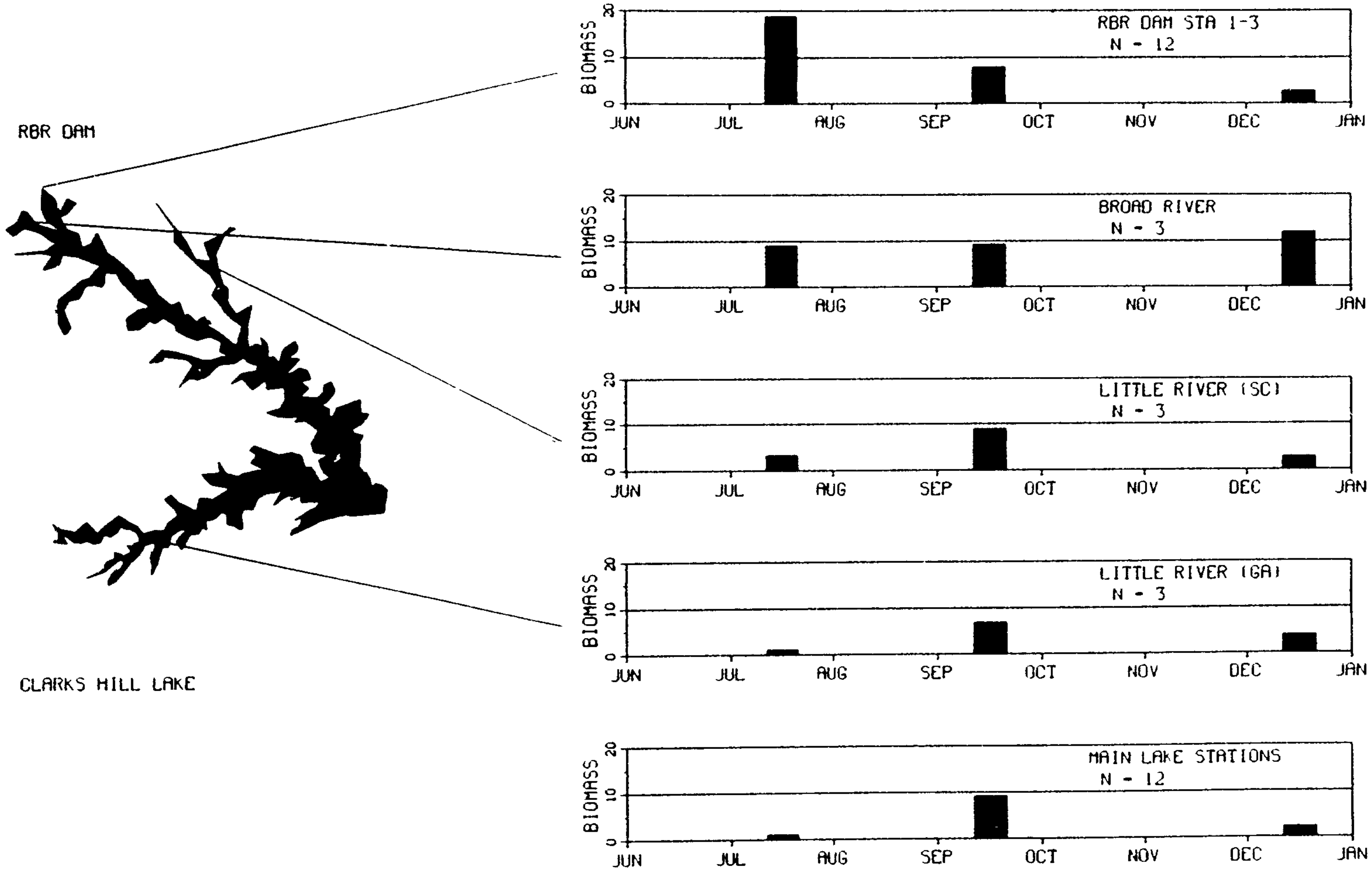


Figure 3. Spatial distribution of largemouth bass catch rates July, September, and December of 1986. Catch rates (kilograms/hour; n = number of electroshocking samples) at each of the major tributaries (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

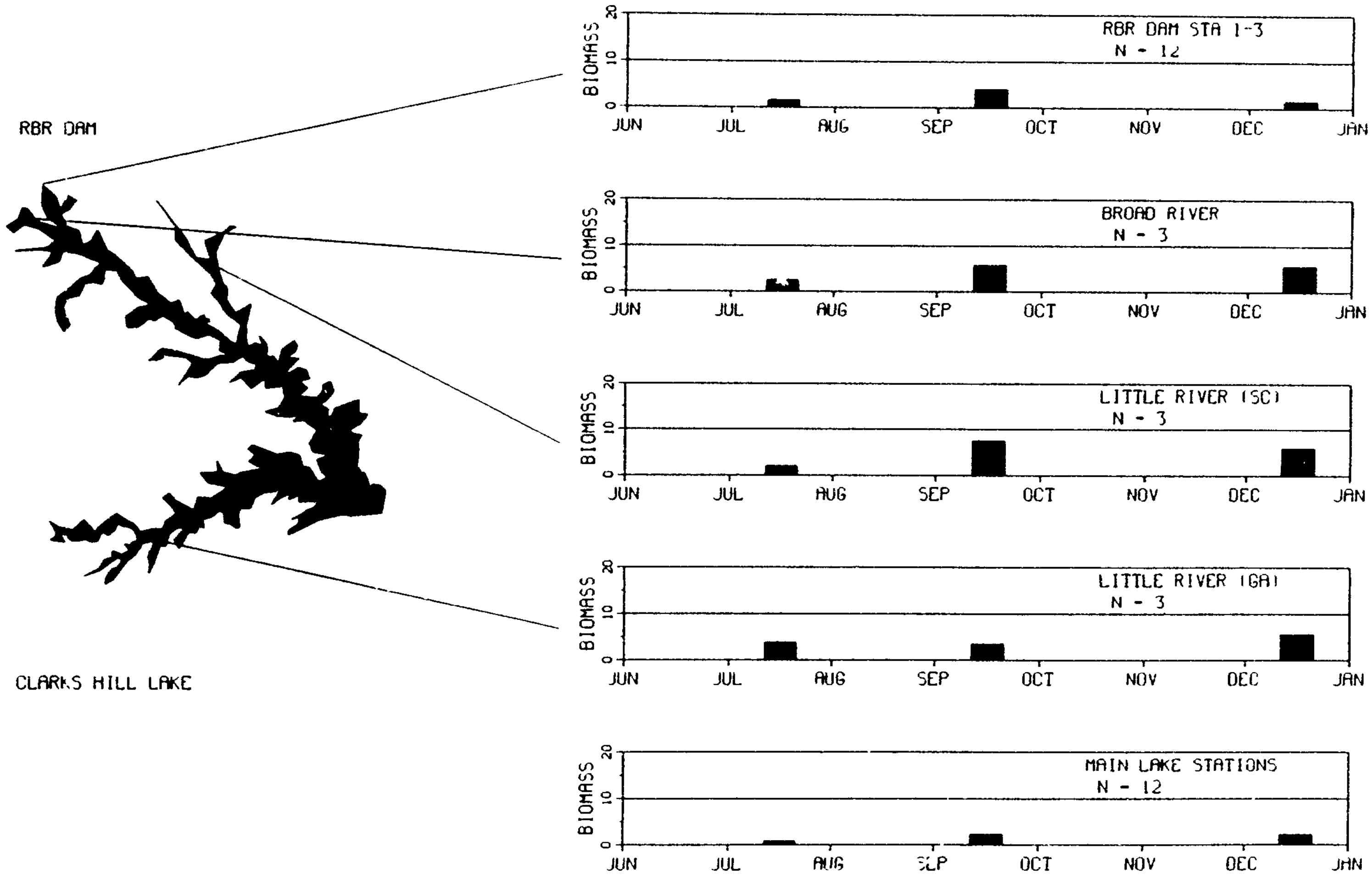


Figure 4. Spatial distribution of bluegill catch rates July, September, and December of 1986. Catch rates (kilograms/hour; n - number of electroshocking samples) at each of the major tributaries (Savannah River--Station 1; Broad River--Station 5; Little River, S.C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

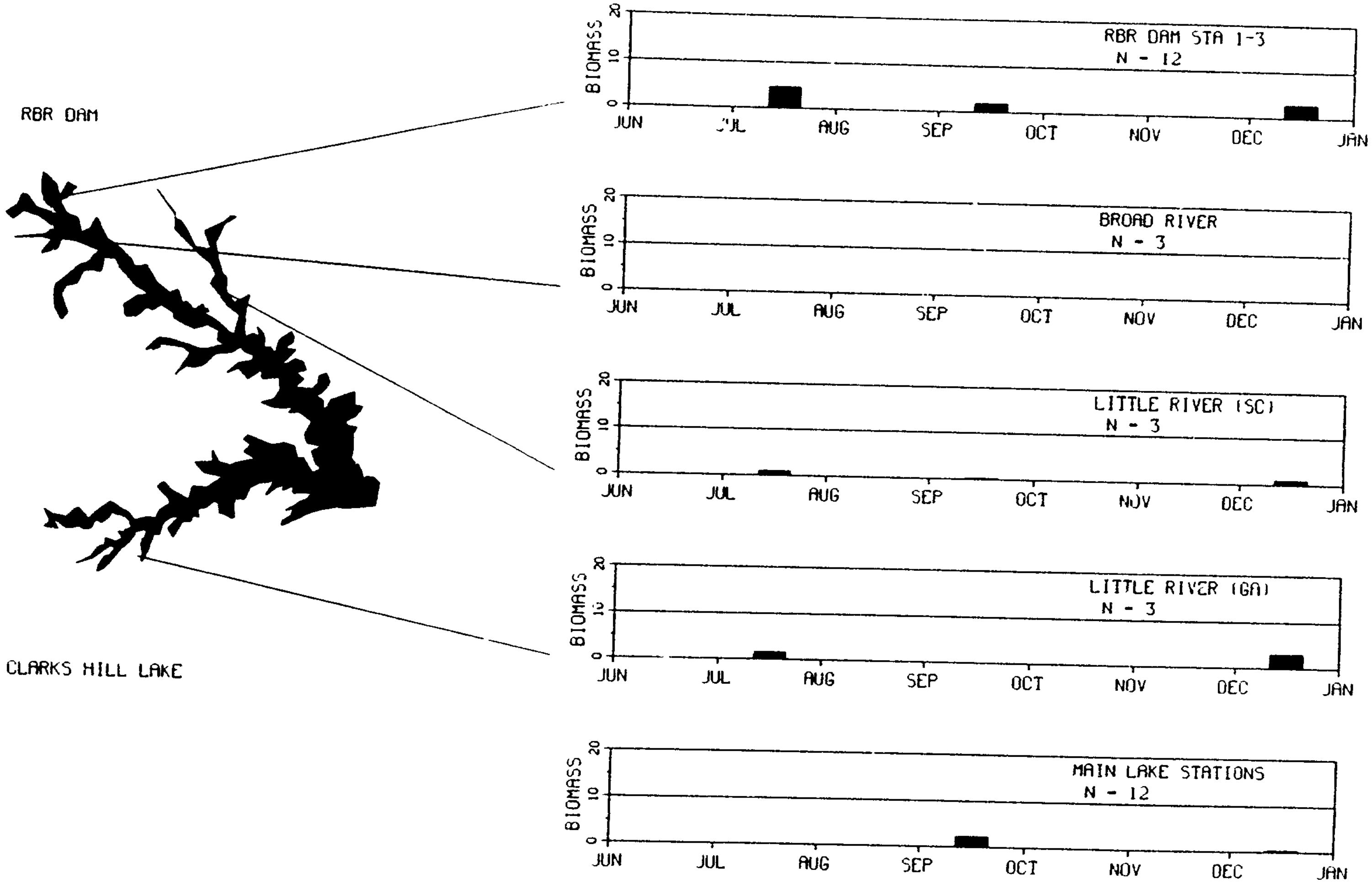


Figure 5. Spatial distribution of gizzard shad catch rates in July, September, and December of 1986. Catch rates (kilograms/hour; n = number of electroshocking samples) at each of the major tributaries (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

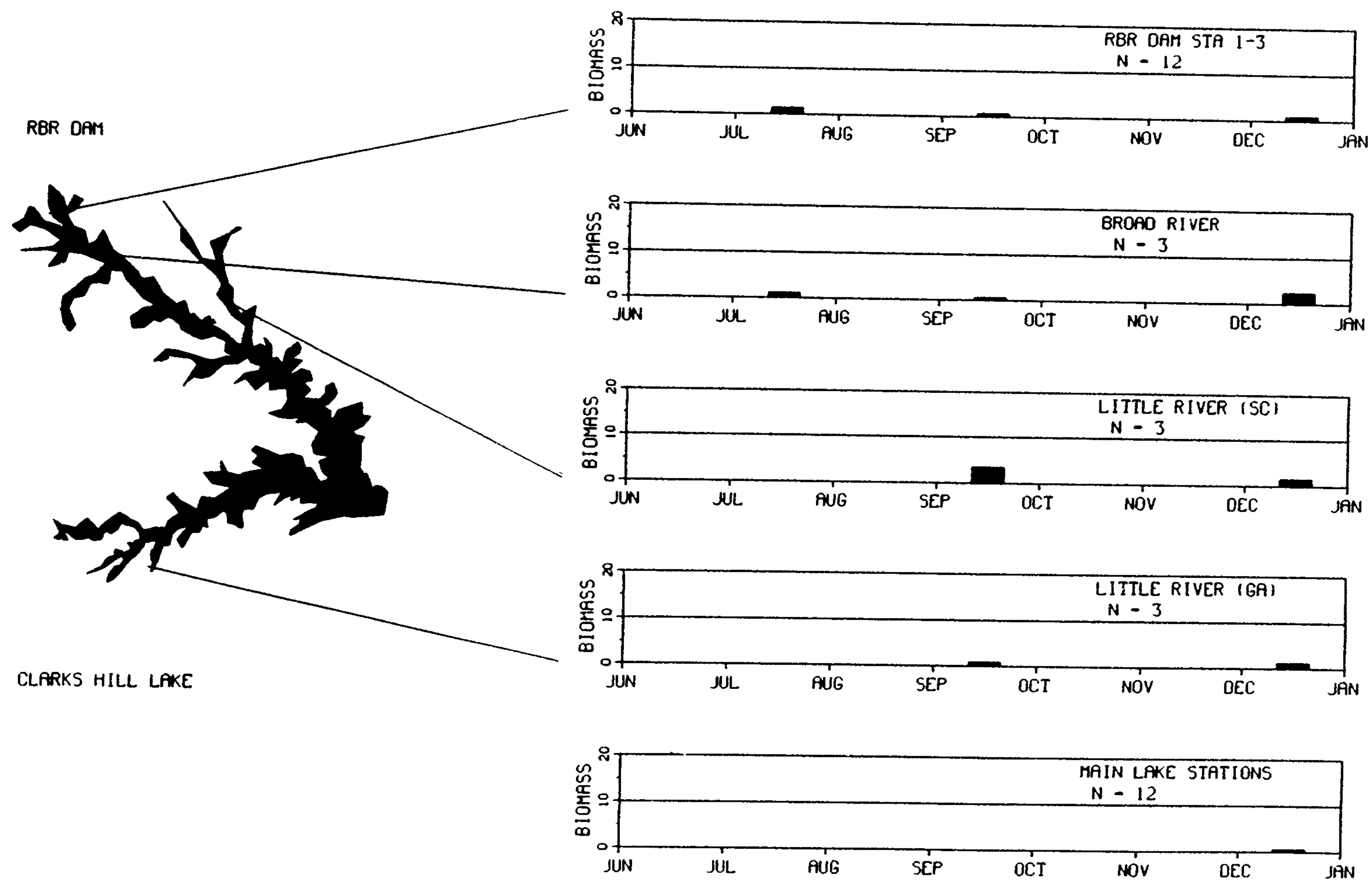


Figure 6. Spatial distribution of redear sunfish catch rates in July, September, and December. Catch rates (kilograms/hour; n = number of electroshocking samples) at each of the major tributaries (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

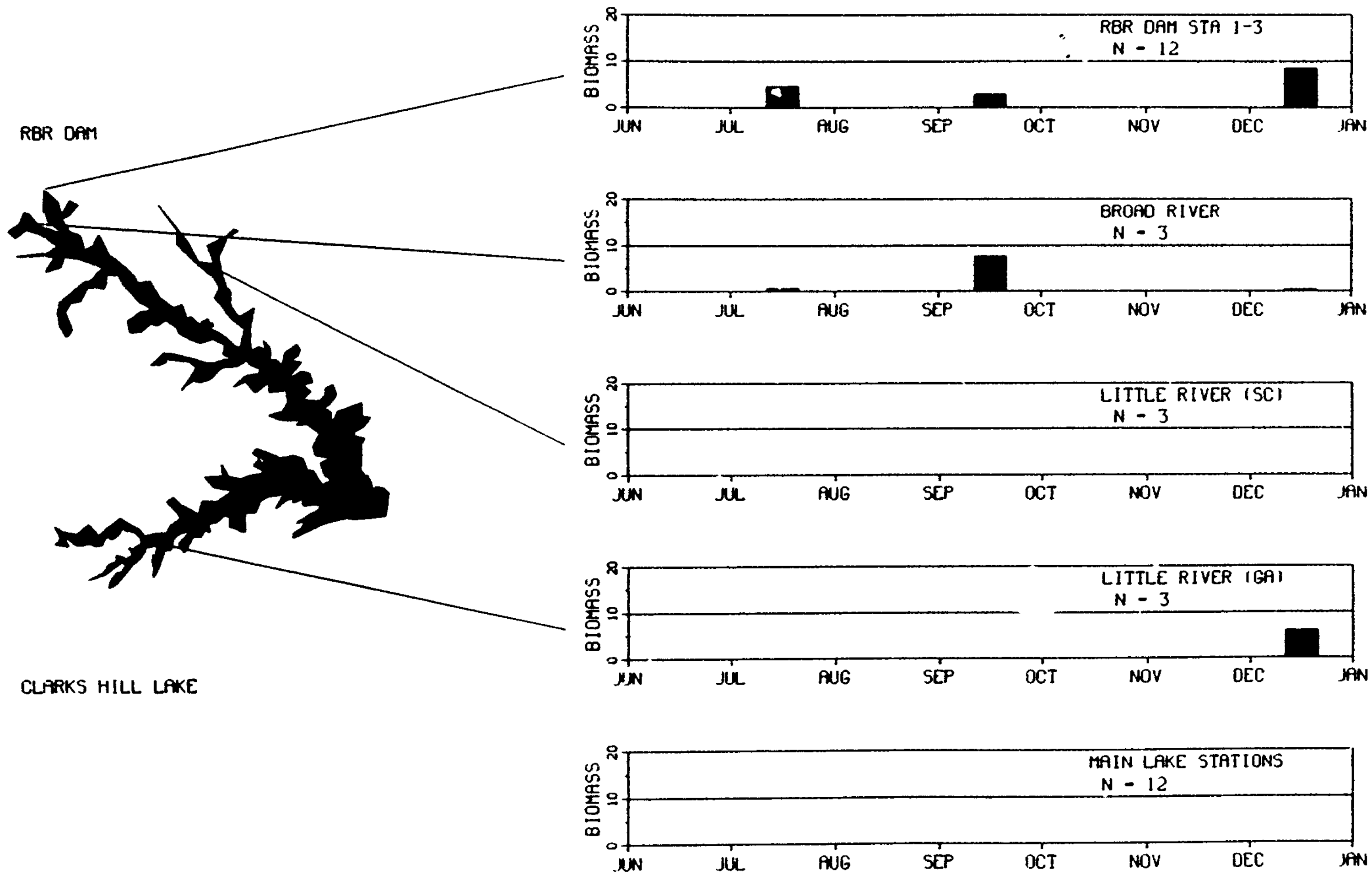


Figure 7. Spatial distribution of silver redhorse catch rates in July, September, and December of 1986. Catch rates (kilograms/hour; n = number of electroshocking samples) at each of the major tributaries (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

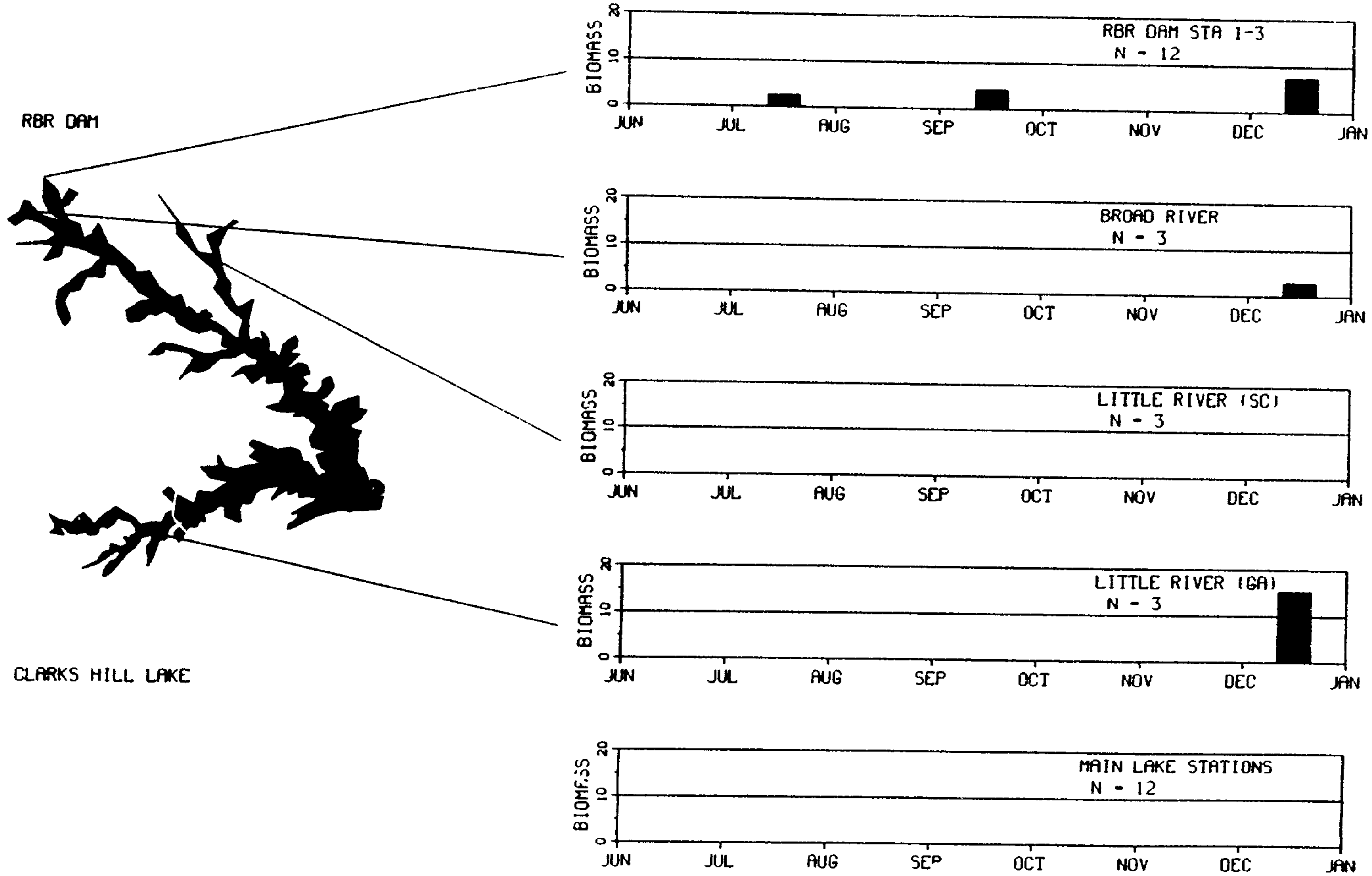


Figure 8. Spatial distribution of spotted sucker catch rates in July, September, and December. Catch rates (kilograms/hour; n = number of electroshocking samples) at each of the major tributaries (Savannah River--Station 1; Broad River--Station 5; Little River, S. C.--Station 6; and Little River, Ga.) are presented along with mean catch rates for the four main lake stations (Stations 7-10)

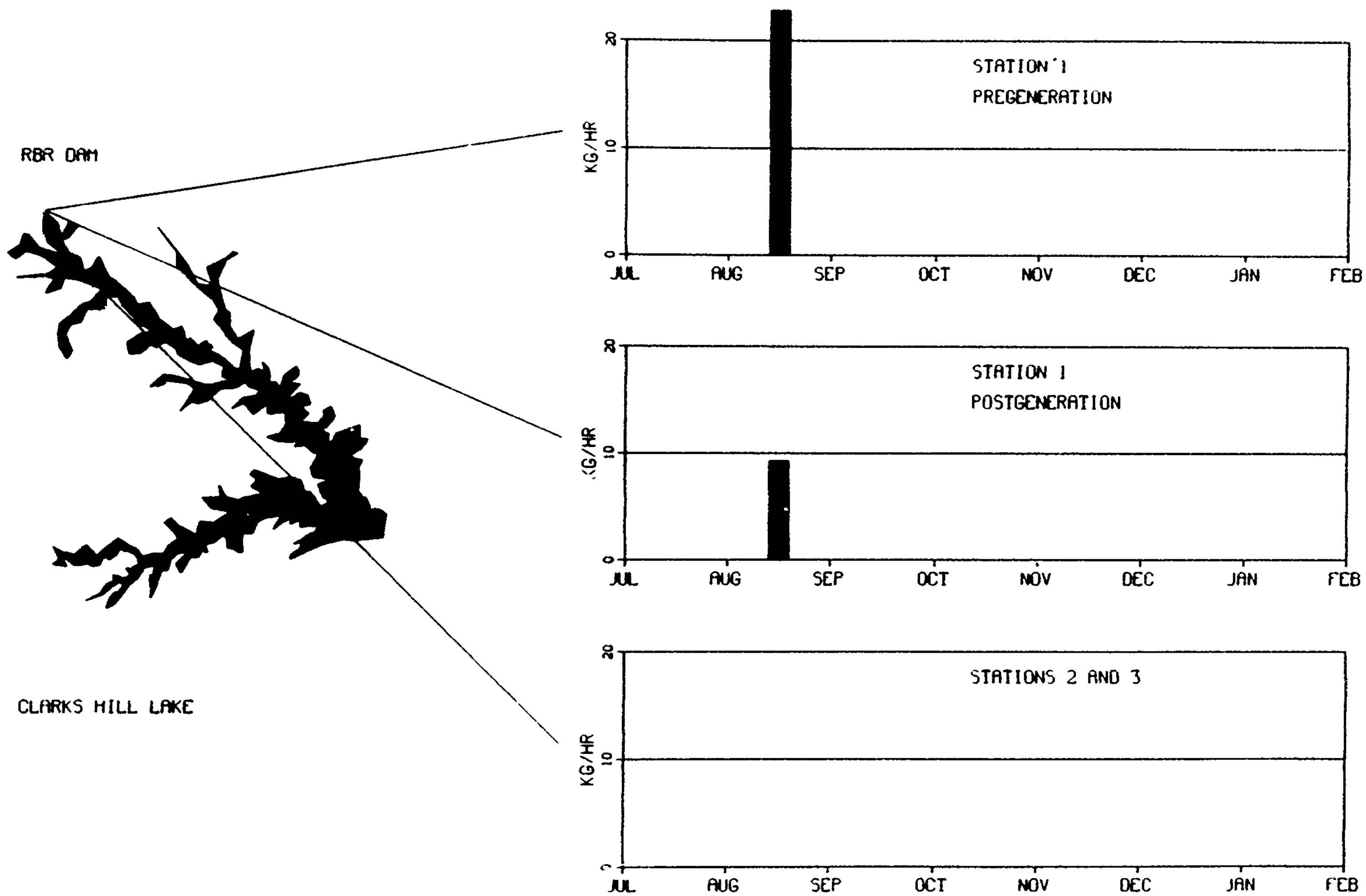


Figure 9. Temporal distribution of hybrid bass catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

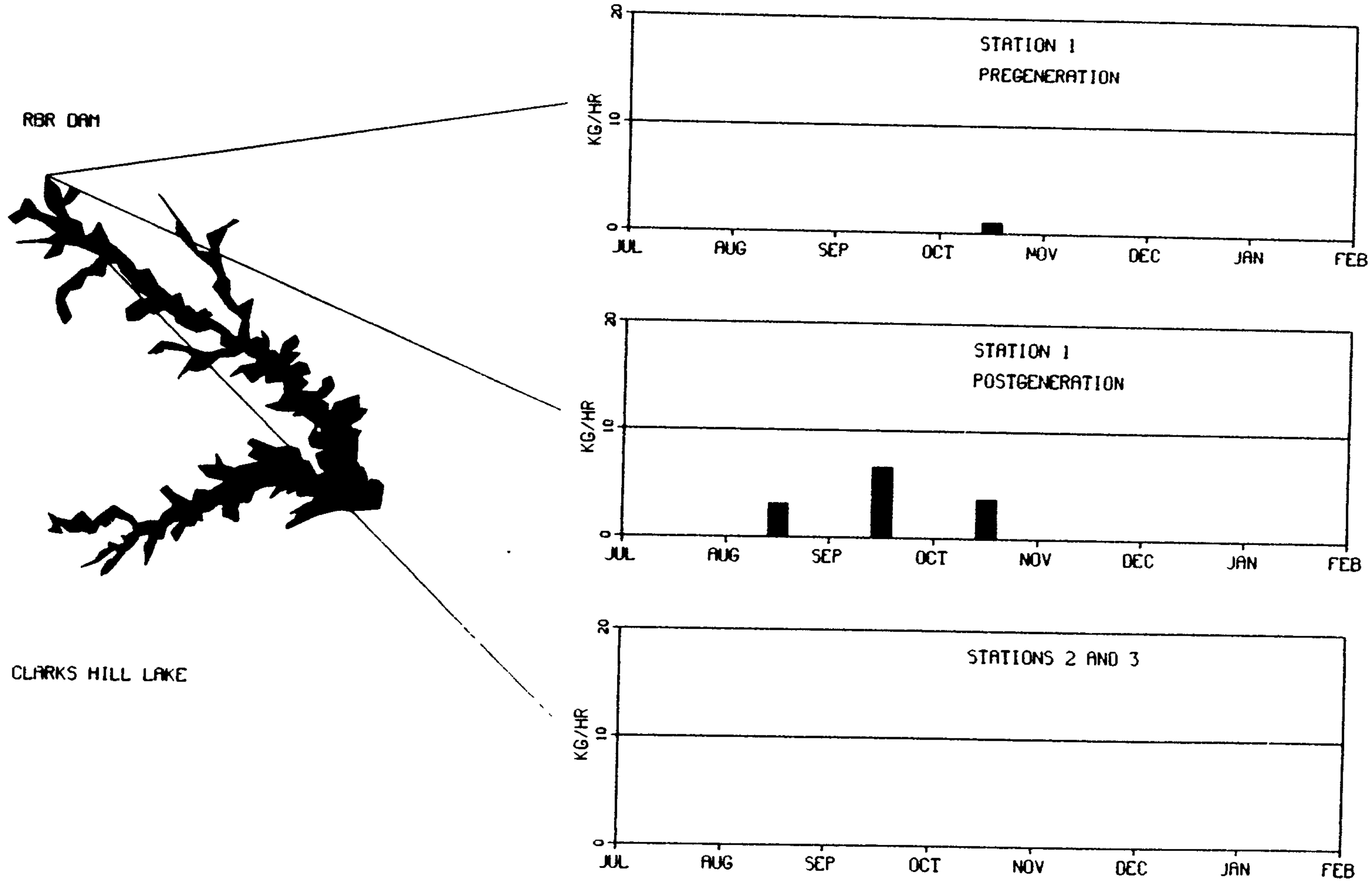


Figure 10. Temporal distribution of striped bass catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

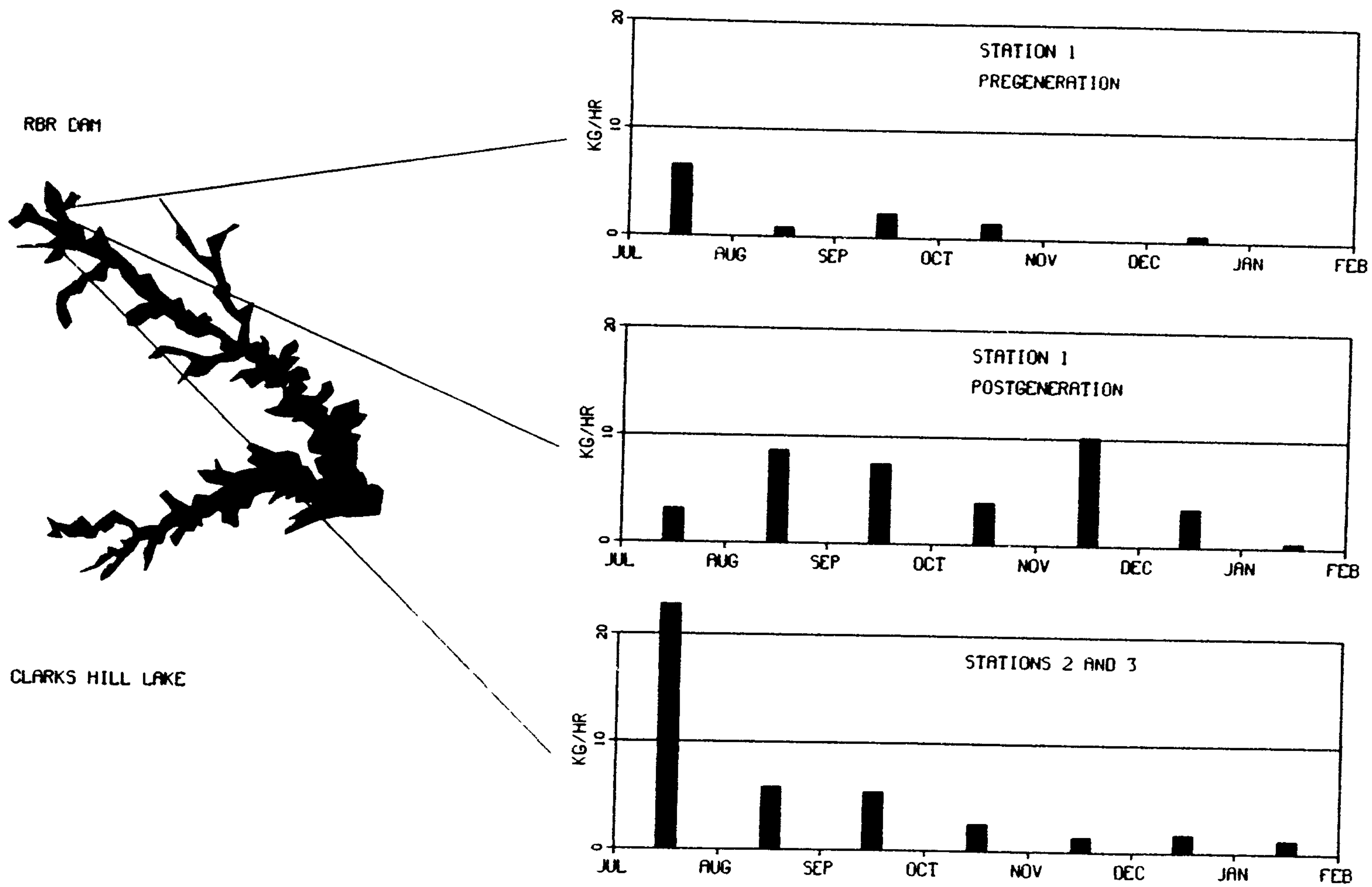


Figure 11. Temporal distribution of largemouth bass catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

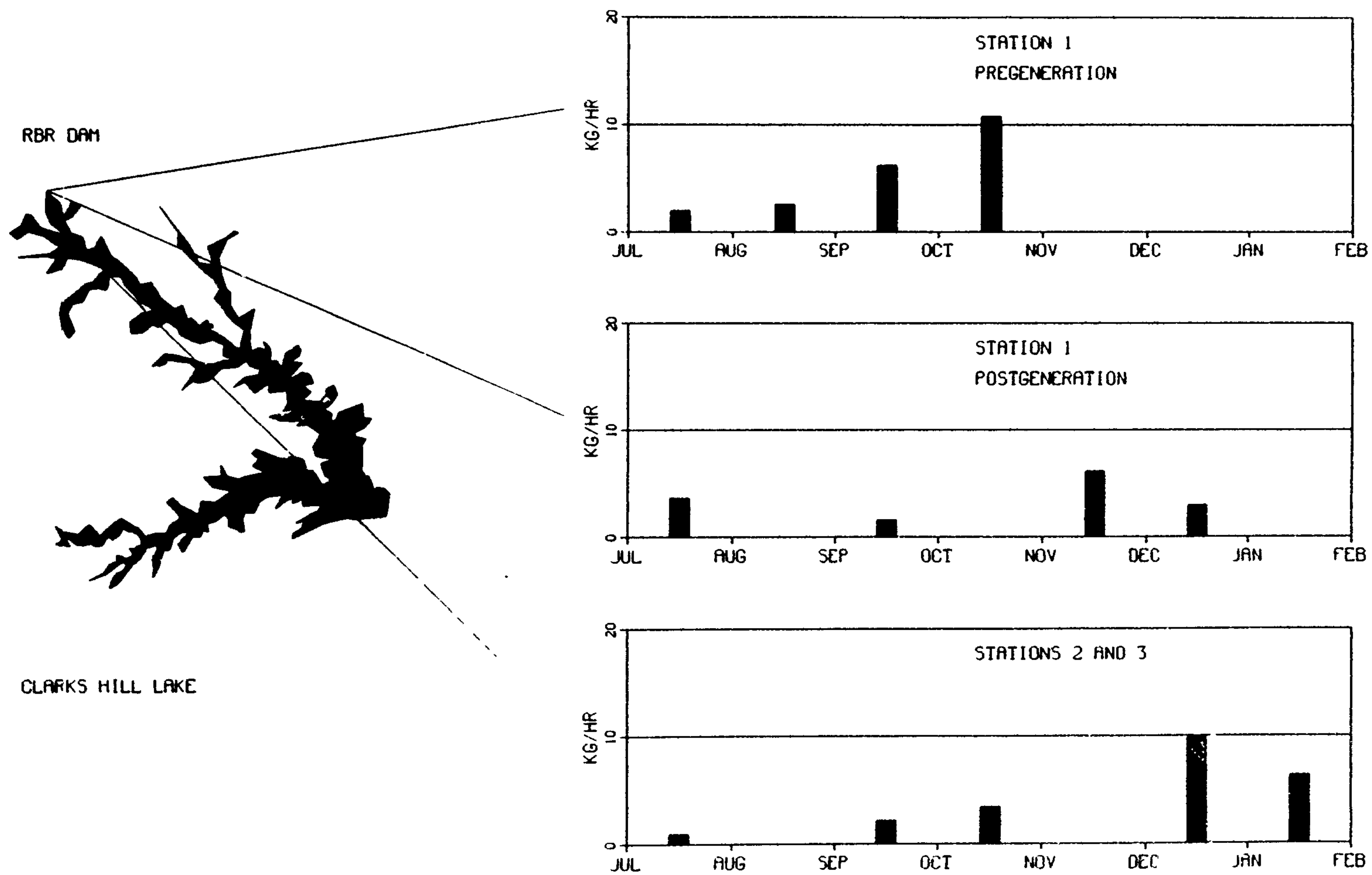


Figure 12. Temporal distribution of spotted sucker catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

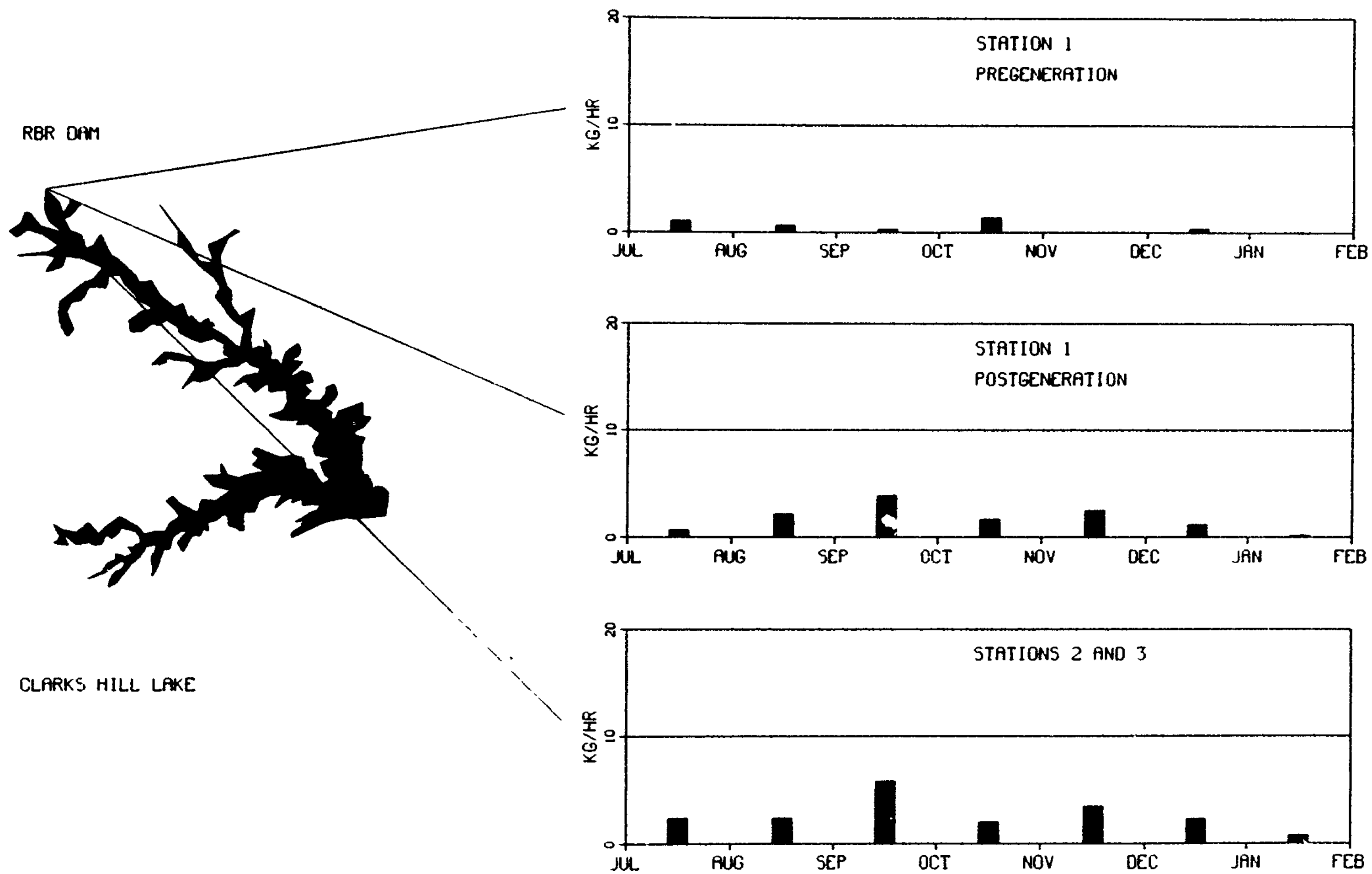


Figure 13. Temporal distribution of bluegill catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

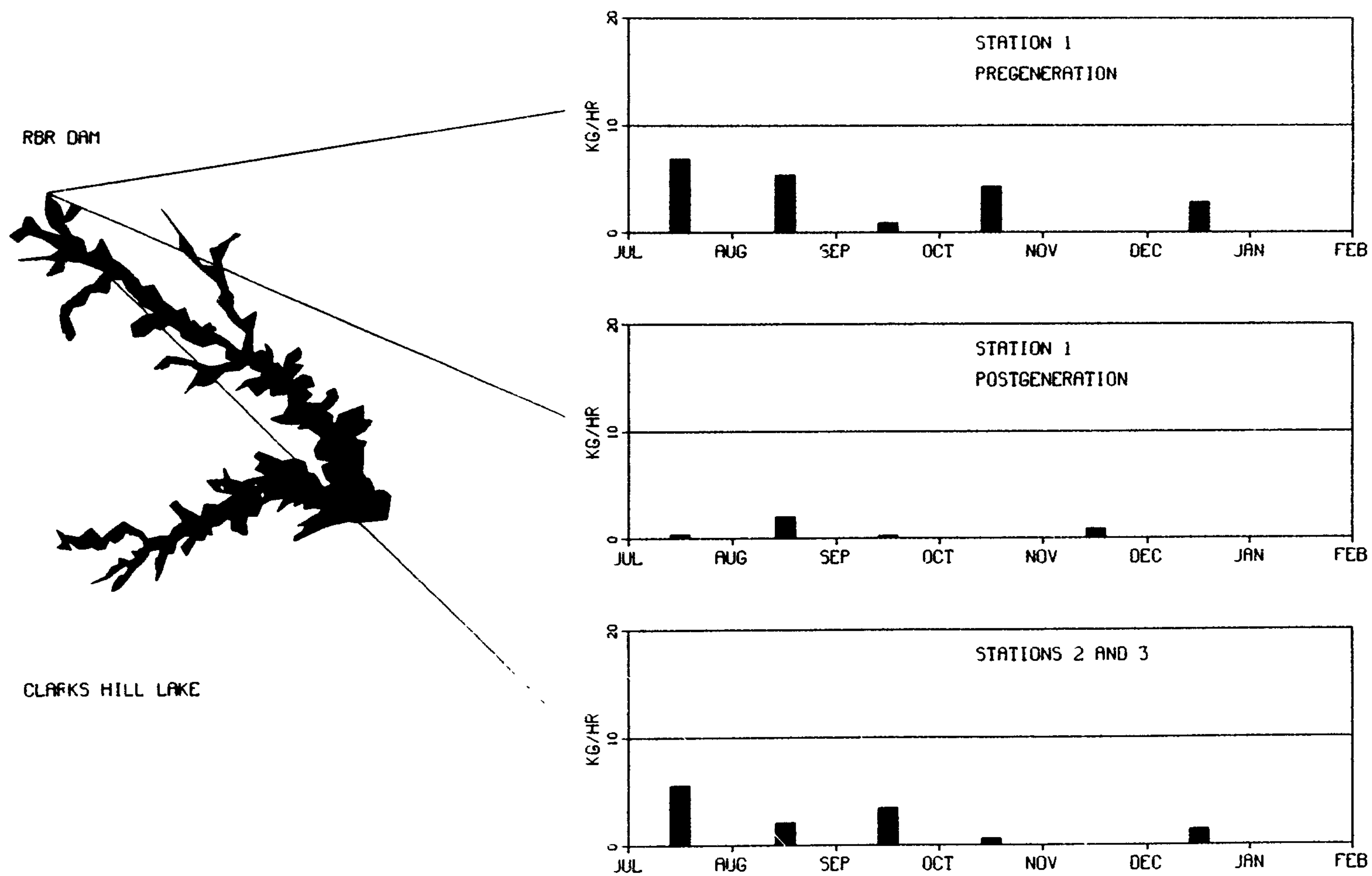


Figure 14. Temporal distribution of gizzard shad catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

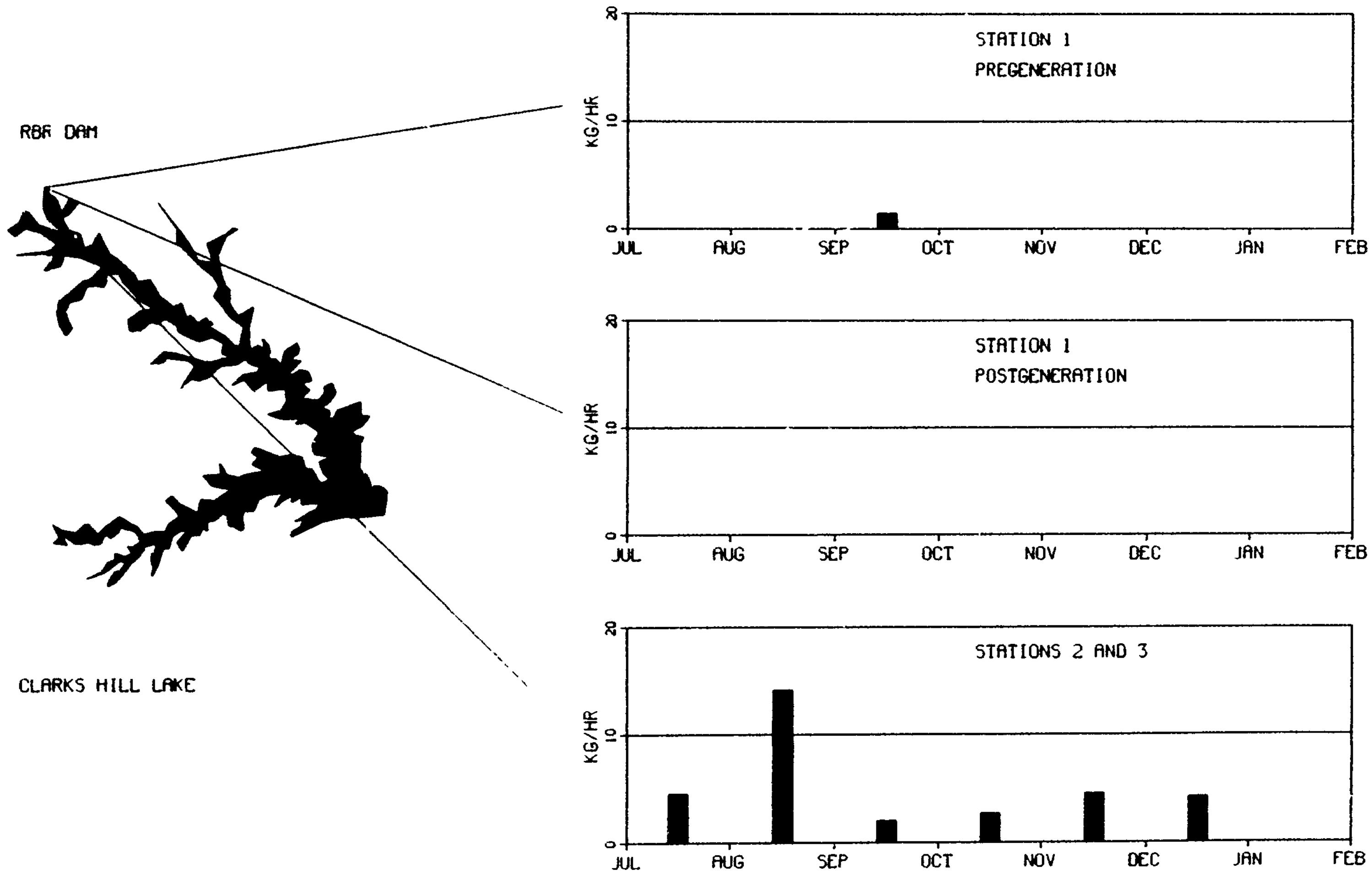


Figure 15. Temporal distribution of silver redhorse catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

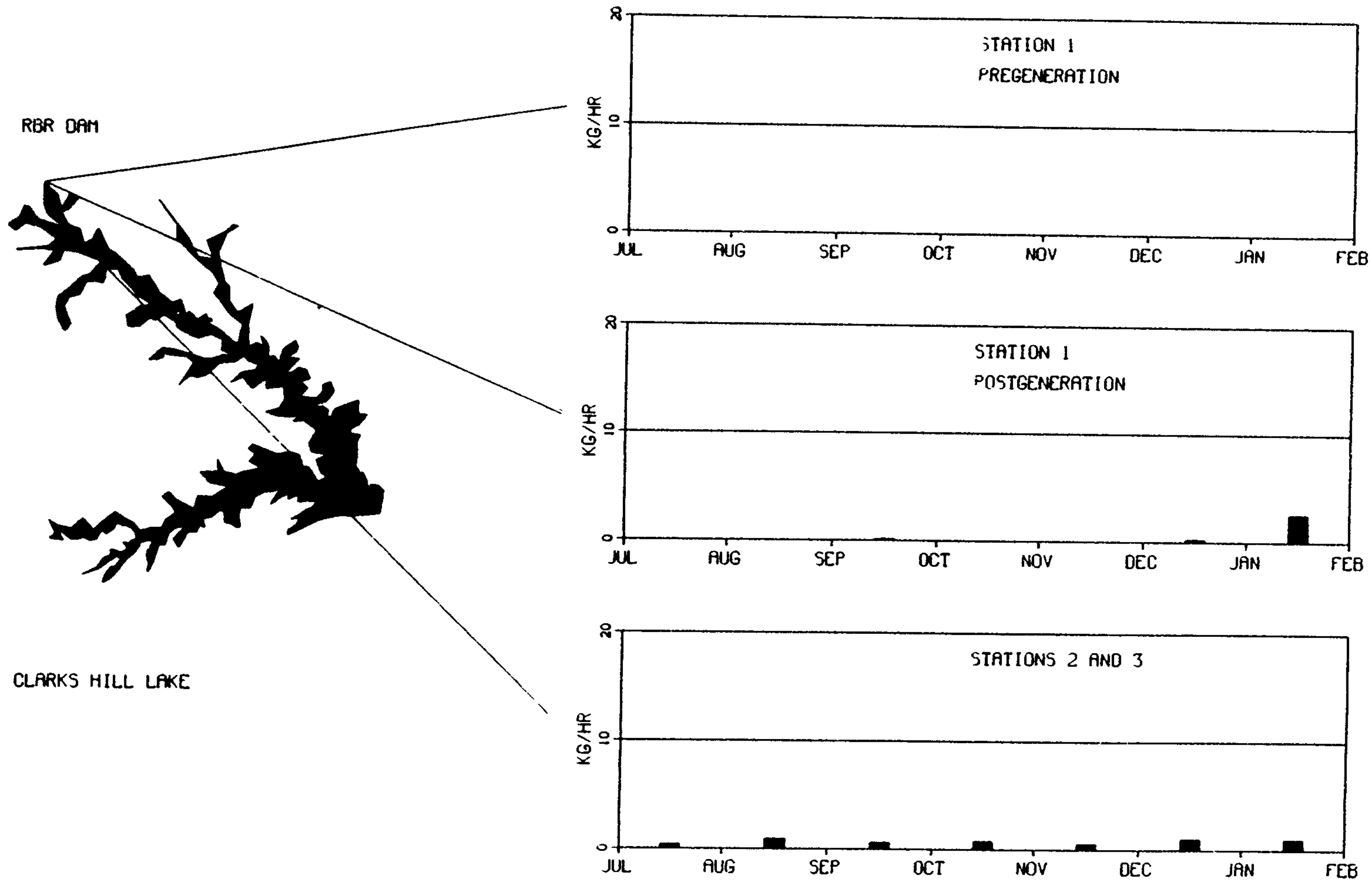


Figure 16. Temporal distribution of yellow perch catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

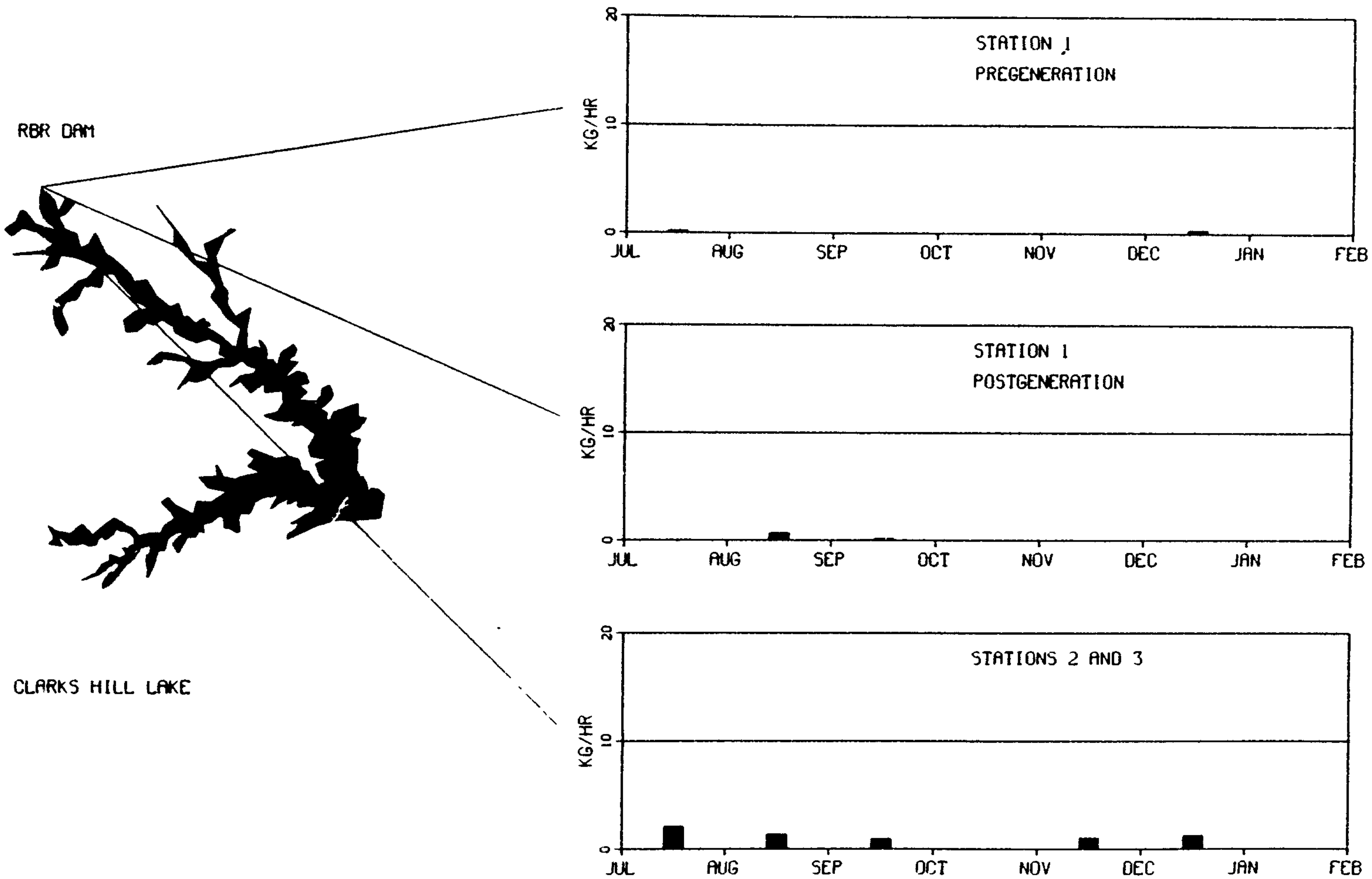


Figure 17. Temporal distribution of redear sunfish catch rates (kilograms/hour) in the tailwater of RBR dam (Stations 1-3) from July 1986-February 1987. Results for Station 1 are presented separately for generation and postgeneration time periods. Results for Stations 2 and 3 are combined

PRELIMINARY RESULTS OF CLARKS HILL LAKE ICHTHYOPLANKTON SAMPLING

M. J. Van Den Avyle and Steven Zimpfer
Georgia Cooperative Fish and Wildlife Research Unit

Introduction

This presentation summarizes results of the first year of ichthyoplankton surveys performed in the Savannah River arm of CHL. Ichthyoplankton surveys can be used to describe the timing and magnitude of reproduction for various species of fishes, particularly those having pelagic early life stages. The tailwater ichthyoplankton surveys have two purposes: (a) to obtain an estimate of the reproductive potential of the Savannah River arm of CHL and thereby estimate the potential effect of pumped-storage operation of RBR on the early life stages of some species and (b) to describe seasonal distribution of ichthyoplankton with the goal of evaluating the feasibility of operational criteria.

Methods

The 1986 ichthyoplankton samples were collected from five sites (Figure 1): (a) the RBR Forebay (Station 0), (b) the immediate tailrace area between the buoy line and dam face (Station 1), (c) the tailrace between Buoys 147 and 148 (Station 2), (d) the tailrace near Buoy 140 (Station 3), and (e) Russell Creek above the Mt. Pleasant boat ramp (Station 4). Collection

sites were visited during daylight hours every 2 weeks from 27 February to 2 July 1986. Additional collections were scheduled for 1987 and 1988, both in the Savannah River arm of CHL and at other tributary and main lake stations.

Four samples were collected at each station using a conical (0.5-m diam) net of 0.505-mm nitex mesh. For each sample, the net was dropped to the bottom and then towed at a constant rate (approximately 1 m/sec) within each of the 1-m-depth intervals in the water column. The amount of towing time spent in each interval was calculated by dividing the number of intervals into 10 min (the total duration of each tow). Beginning with the deepest depth interval, each interval was sampled for the calculated time, at which point the net was stepped up to the next depth interval. This sampling procedure continued until a pooled sample was collected for the entire water column. Towing speed and duration were designed to achieve a target sample volume of approximately 100 m^3. A flowmeter in the mouth of the net yielded estimates of volume filtered that ranged from 52 to 123 m^3. The contents of each sample were washed into 1-l glass jars and preserved in 5-percent formalin. In the lab, each specimen was indentified to the lowest possible taxon and assigned to one of the following categories: (a) egg, (b) larva (protolarva, mesolarva, and metalarva), and (c) juvenile. The 1986 samples were collected by WES personnel stationed at the RBR lab and were archived for later processing. Samples were later picked and processed by the FWS Georgia Cooperative Fisheries and Wildlife Research Unit.

Results and Discussion

In 1986, 395 larvae were collected from the five stations near the tailrace. Over 95 percent of the total catch was composed of four taxonomic groups: Clupeidae, yellow perch, black crappie, and Lepomis spp. (Figure 2). Clupeids were most abundant (n = 164) and may have included gizzard shad, threadfin shad, and blueback herring as their early life stages were indistinguishable. Yellow perch (n = 100) was second in abundance, followed by black crappie (n = 87), and sunfishes (n = 27). Other taxa collected included white crappie, white bass, common carp, and an unidentified darter.

Several species common as adults in gillnet and electrofishing surveys were absent from the ichthyoplankton samples. They included hybrids, striped bass, sauger, largemouth bass, longnose gar, and river carpsucker. The absence of certain larvae (e.g., hybrid bass, striped bass, and sauger) might reflect lack of successful natural reproduction, and the absence of others (e.g., largemouth bass and longnose gar) might indicate sampling selectivity.

Larval fish densities were greatest at Russell Creek (Station 4), the only tributary station near the tailrace (Figure 3). Over 70 percent of the total catch was taken at this station. Densities were lowest in the deep water (50 m) of the RBR forebay (Station 0) and in the immediate tailrace below the dam (Station 1). Abundance at tailrace stations increased with distance from the dam; 41 larvae were collected at Station 2, and 62 larvae were taken at Station 3.

Every common taxonomic group was more abundant at Russell Creek than at any other site. Clupeids were present at all stations, but 67 percent were collected at Station 4 (Figure 4). Samples from Russell Creek also yielded high proportions of larval yellow perch (83 percent), black crappie (65 percent), and *Lepomis* (70 percent) (Figures 5, 6, and 7). These three taxa were absent from Stations 0 and 1; however, white bass larvae were found only at Stations 0 and 1. The importance of Russell Creek as a spawning habitat was further evidenced by temporal trends in abundance. Ichthyoplankton densities were highest there throughout the last 5 months of the survey (Figure 8).

The first species to appear in ichthyoplankton samples was the yellow perch (Figure 9), which was initially collected in early March. Numbers peaked on March 12 at Station 3 and on March 27 at Station 4, but larvae occurred in samples until early May. Black crappie were most abundant in April. Peak numbers were higher than those of the yellow perch, but the spawning season was apparently less extended. Clupeids were most abundant in May and June, with a secondary pulse at Station 4 in April. No larvae were caught in February, and only four were collected during July.

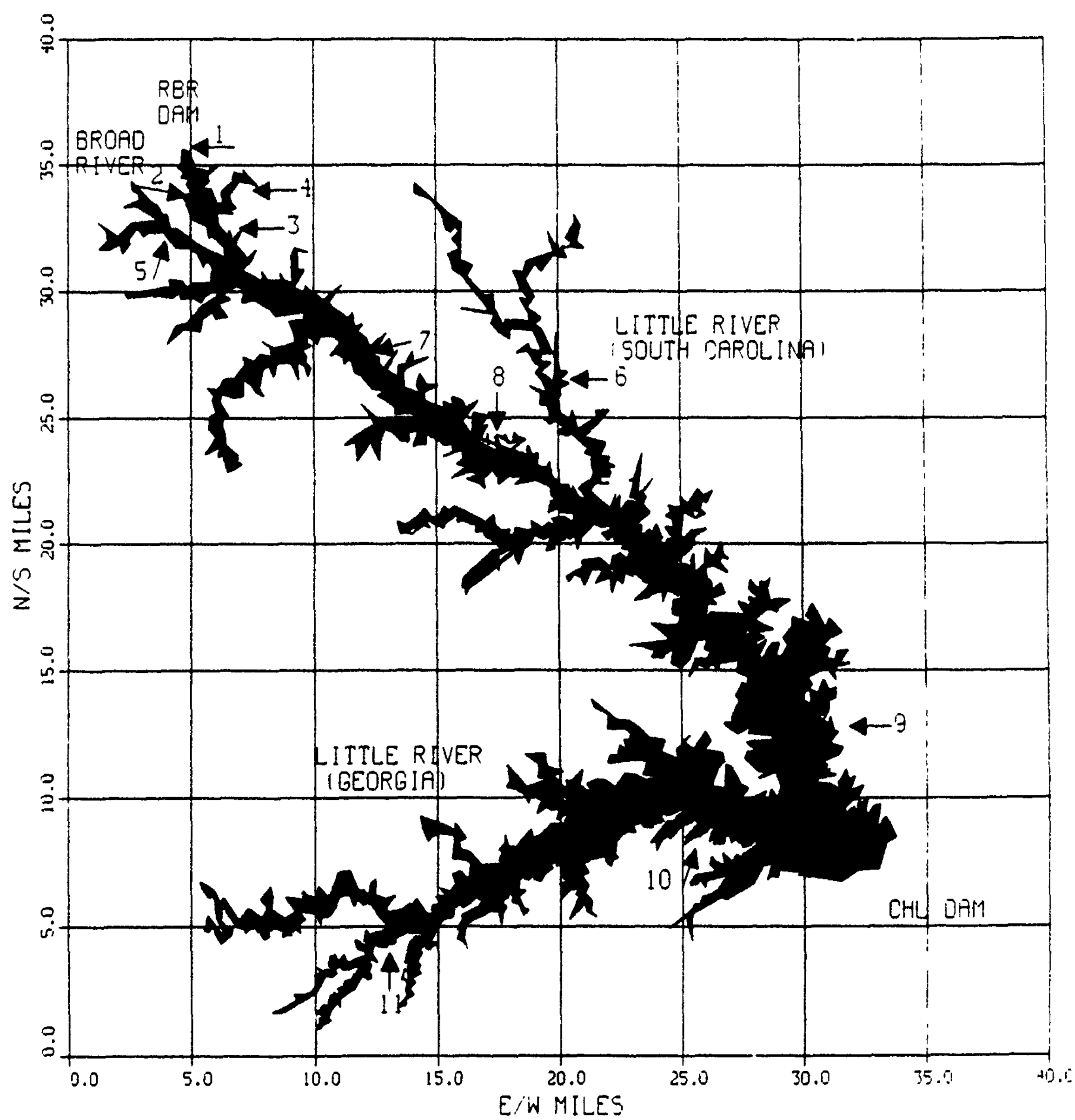


Figure 1. Locations of ichthyoplankton sampling stations in CHL. Station 0 is located in the forebay of RBR dam. Ichthyoplankton sampling in CHL in 1986 was restricted to the Savannah River arm (including Russell Creek-- (Station 4)

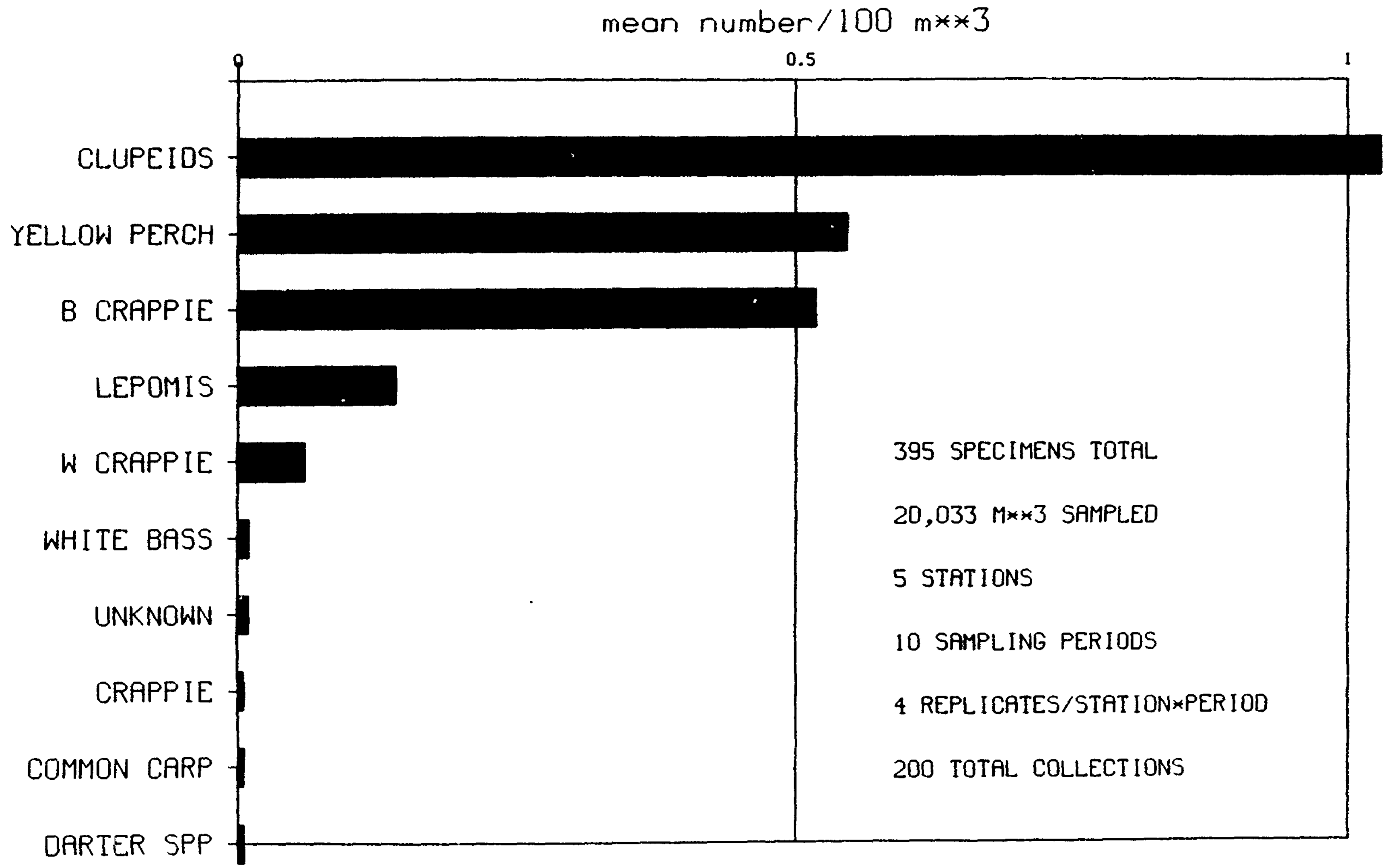


Figure 2. Relative ichthyoplankton composition (mean number/100 m^3), by species, collected from February-July 1986. All stations and sampling times are combined. Note the high relative abundance of Clupeids and yellow perch

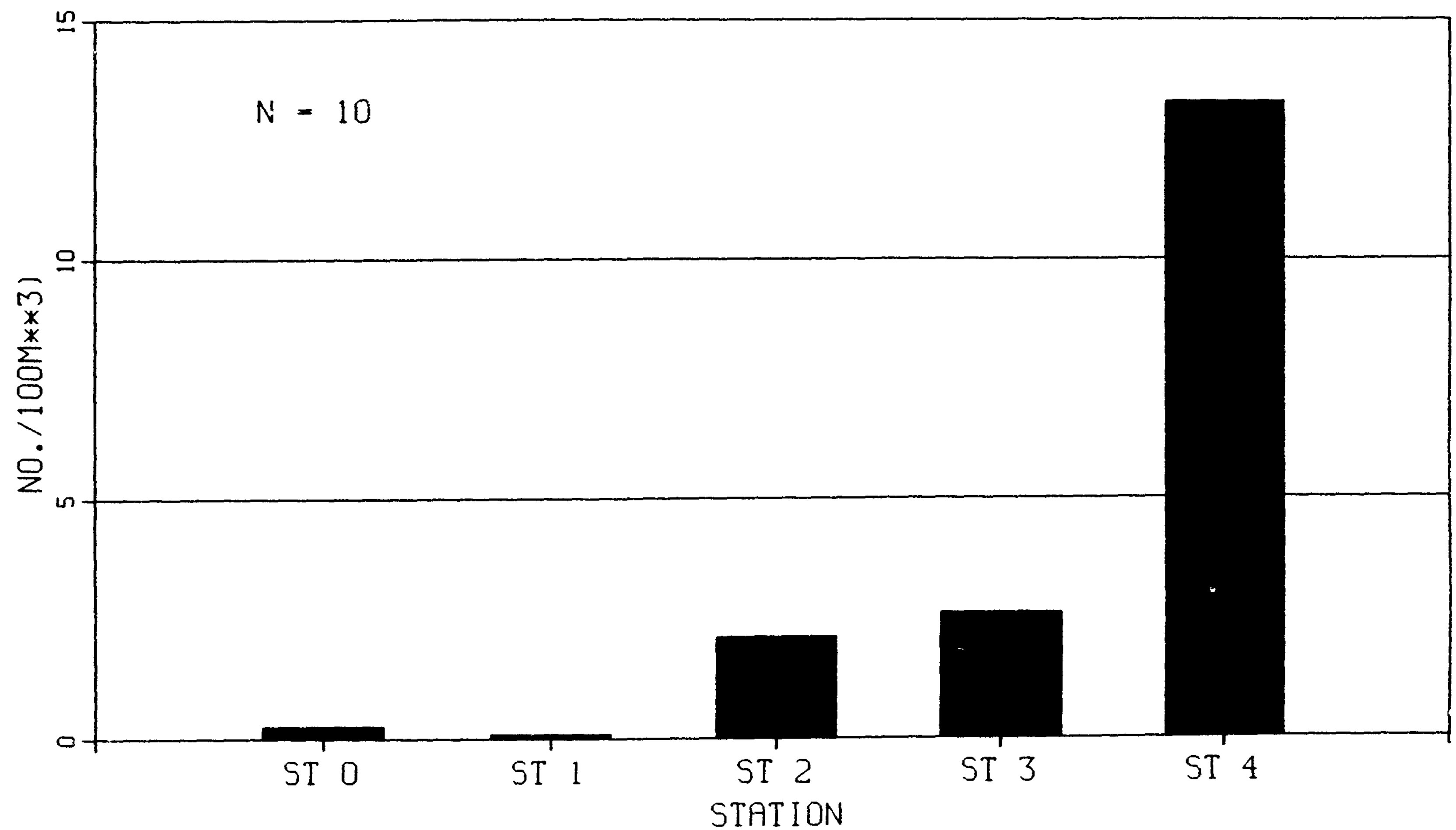


Figure 3. Relative ichthyoplankton abundance (mean number/100 m^3), by station, collected from February-July 1986, all species and times combined. Note the low densities near the dam (Stations 0 and 1) and the high relative density at the station farthest from the dam (Station 4)

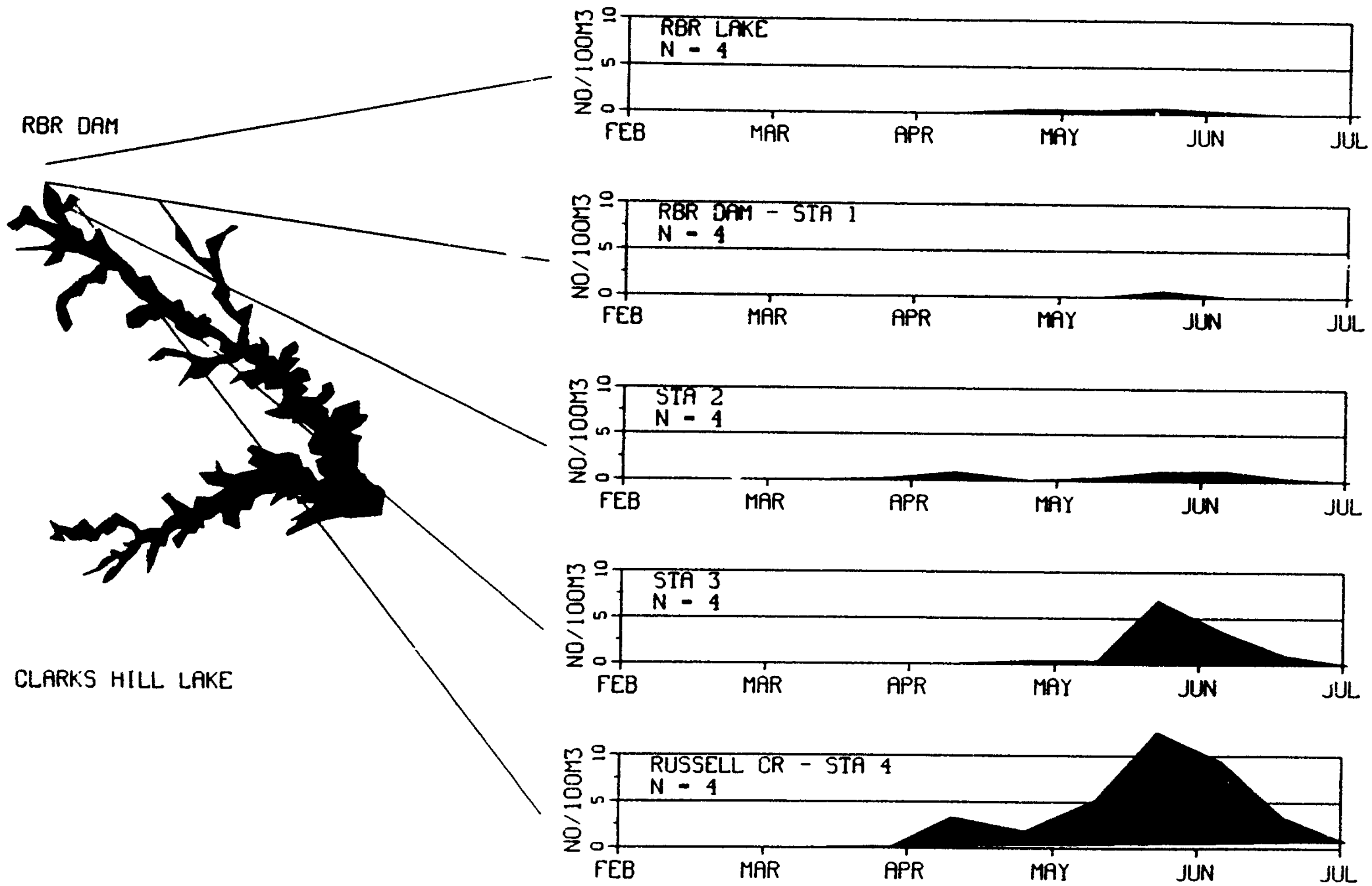


Figure 4. Density of Clupeid ichthyoplankton (mean number/100 m^3), by station, collected from February-July 1986. Note the higher relative abundances at Station 4

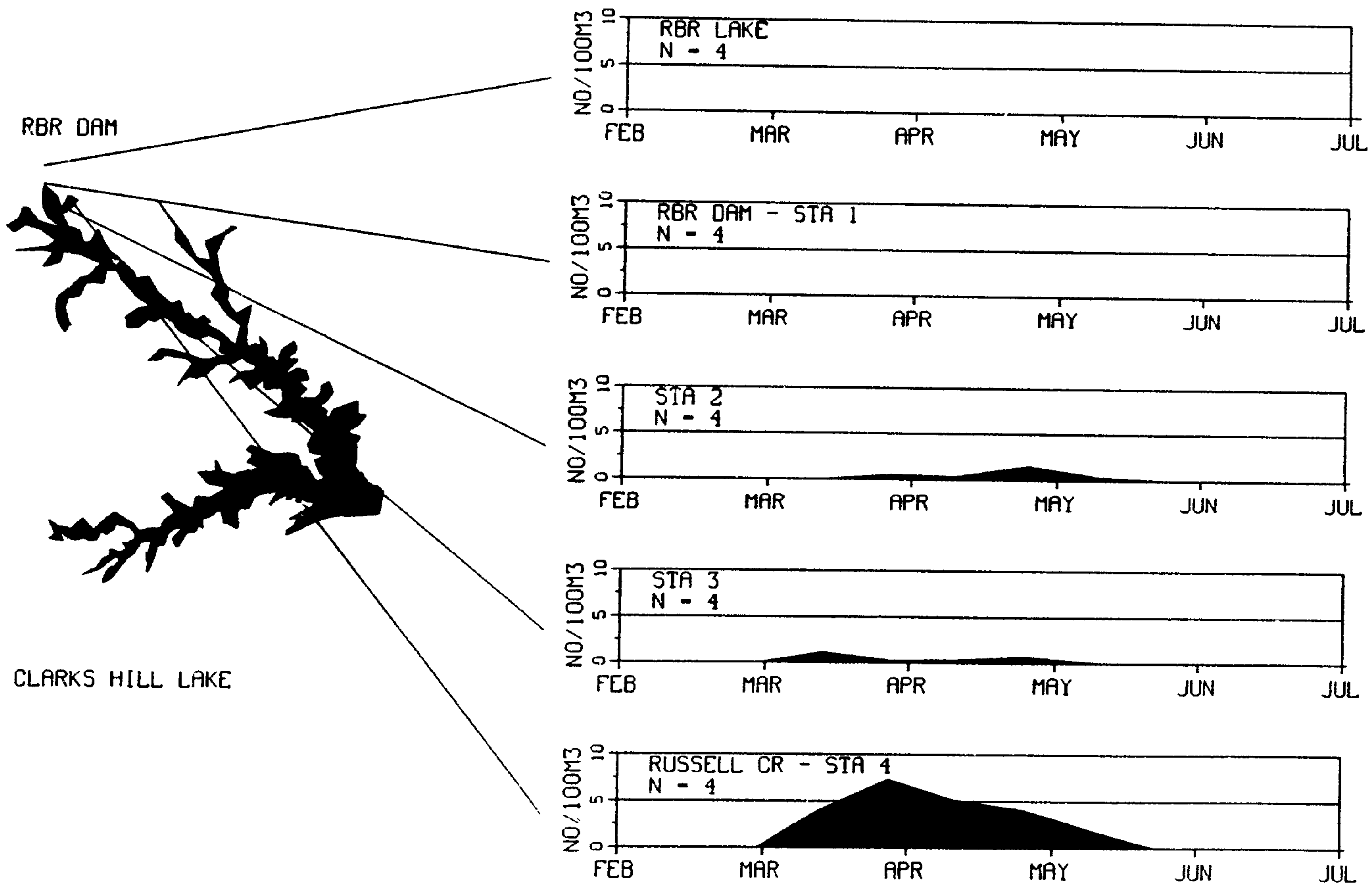


Figure 5. Density of yellow perch ichthyoplankton (mean number/100 m^3), by station, collected from February-July 1986. Note the higher relative abundances at Station 4

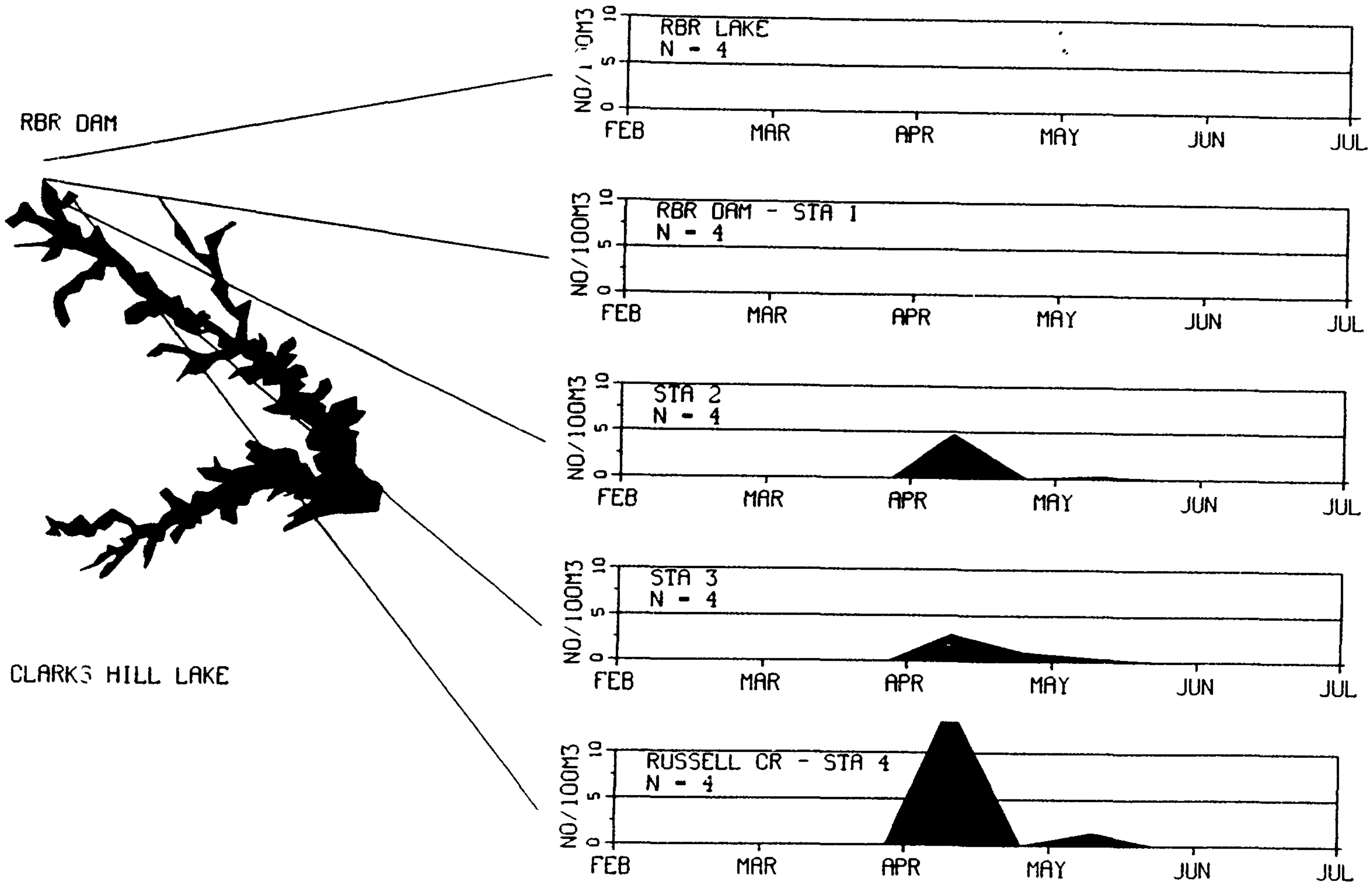


Figure 6. Density of black crappie ichthyoplankton (mean number/100 m^3), by station, collected from February-July 1986. Note the higher relative abundances at Station 4

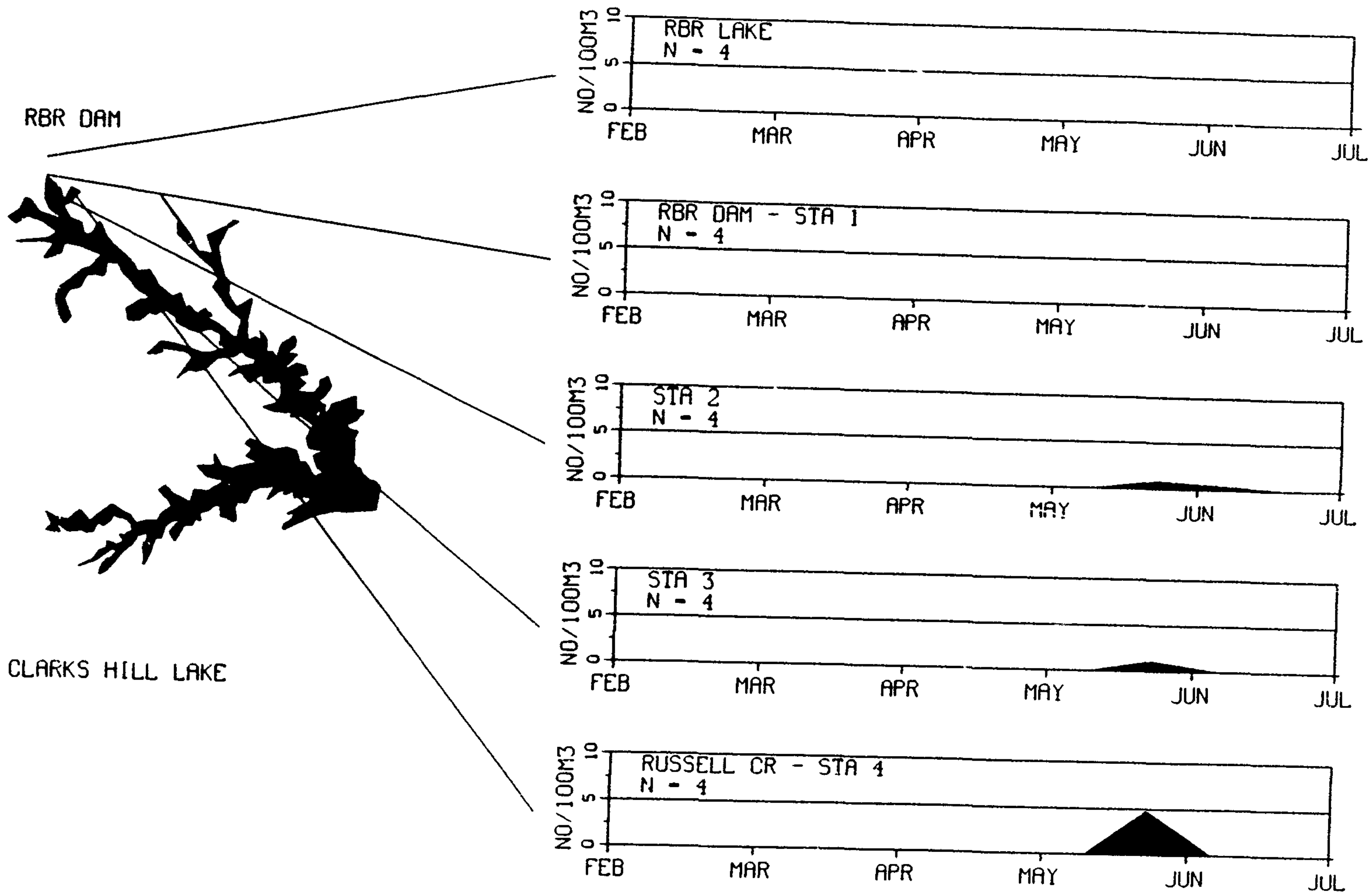


Figure 7. Density of *Lepomis* ichthyoplankton (mean number/100 m^3), by station, collected from February-July 1986. Note the higher relative abundances at Station 4

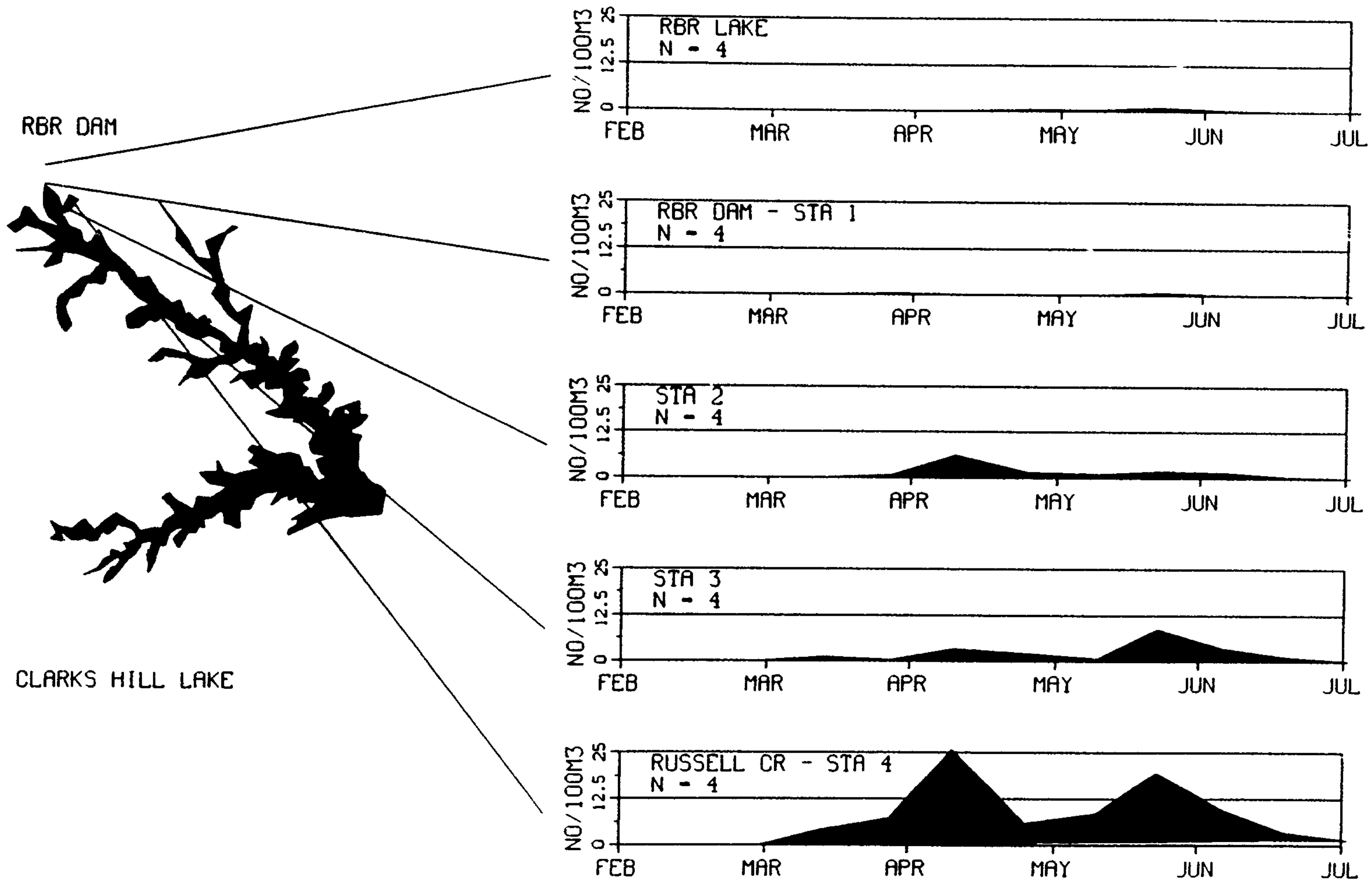


Figure 8. Density of ichthyoplankton (mean number/100 m^3), by station, collected from February-July 1986. Results are for all species combined. Note the higher relative abundances at Station 4

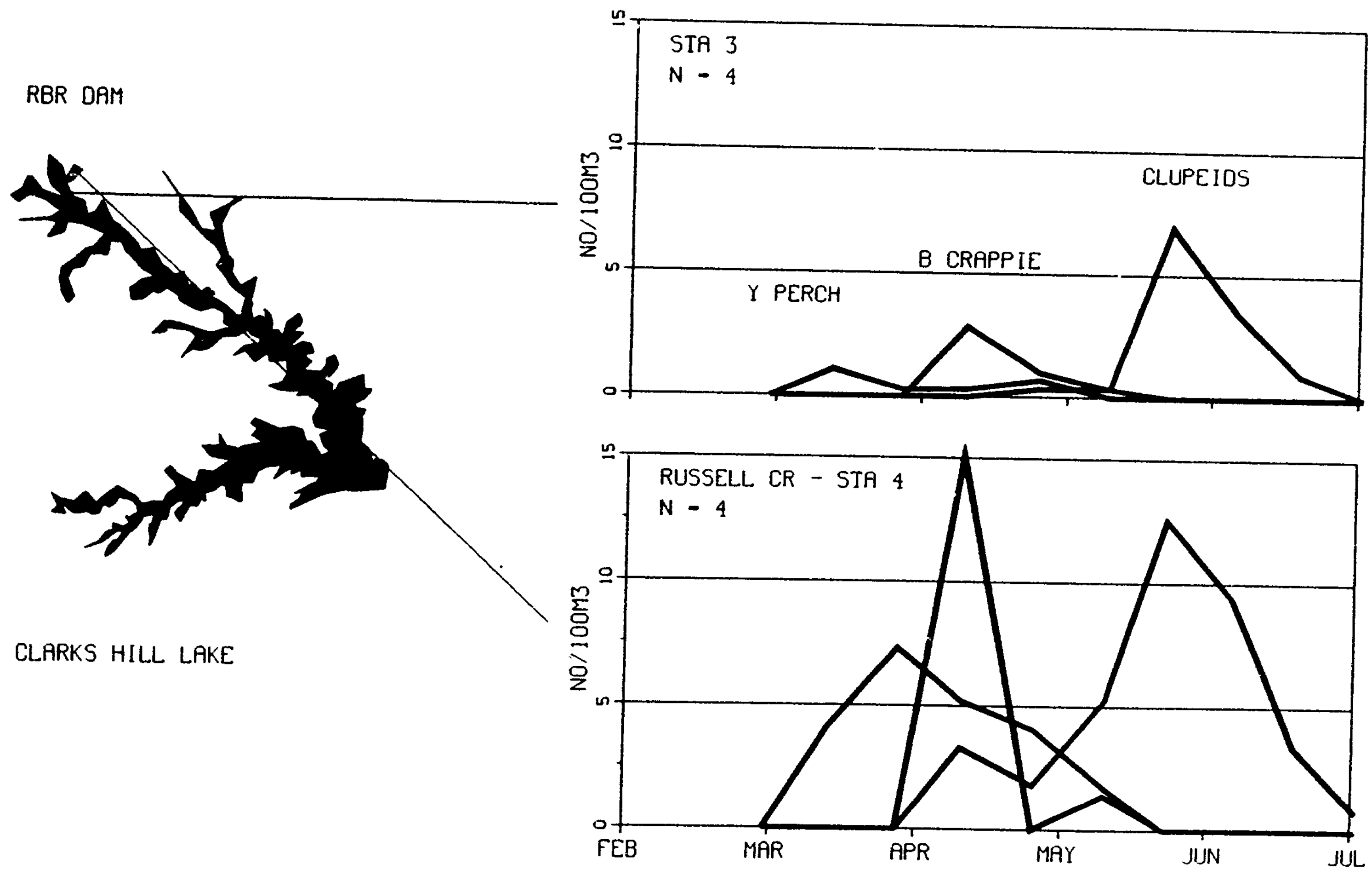


Figure 9. Temporal abundances (mean number/100 m^3) of yellow perch, black crappie, and Clupeid ichthyoplankton at Stations 3 and 4. Note that each species has a separate peak. Sequence of species is the same for Station 4 as for Station 3

RESULTS OF COVE ROTENONE SAMPLING

M. J. Van Den Avyle and T. J. Welch

Georgia Cooperative Fish and Wildlife Research Unit

Introduction

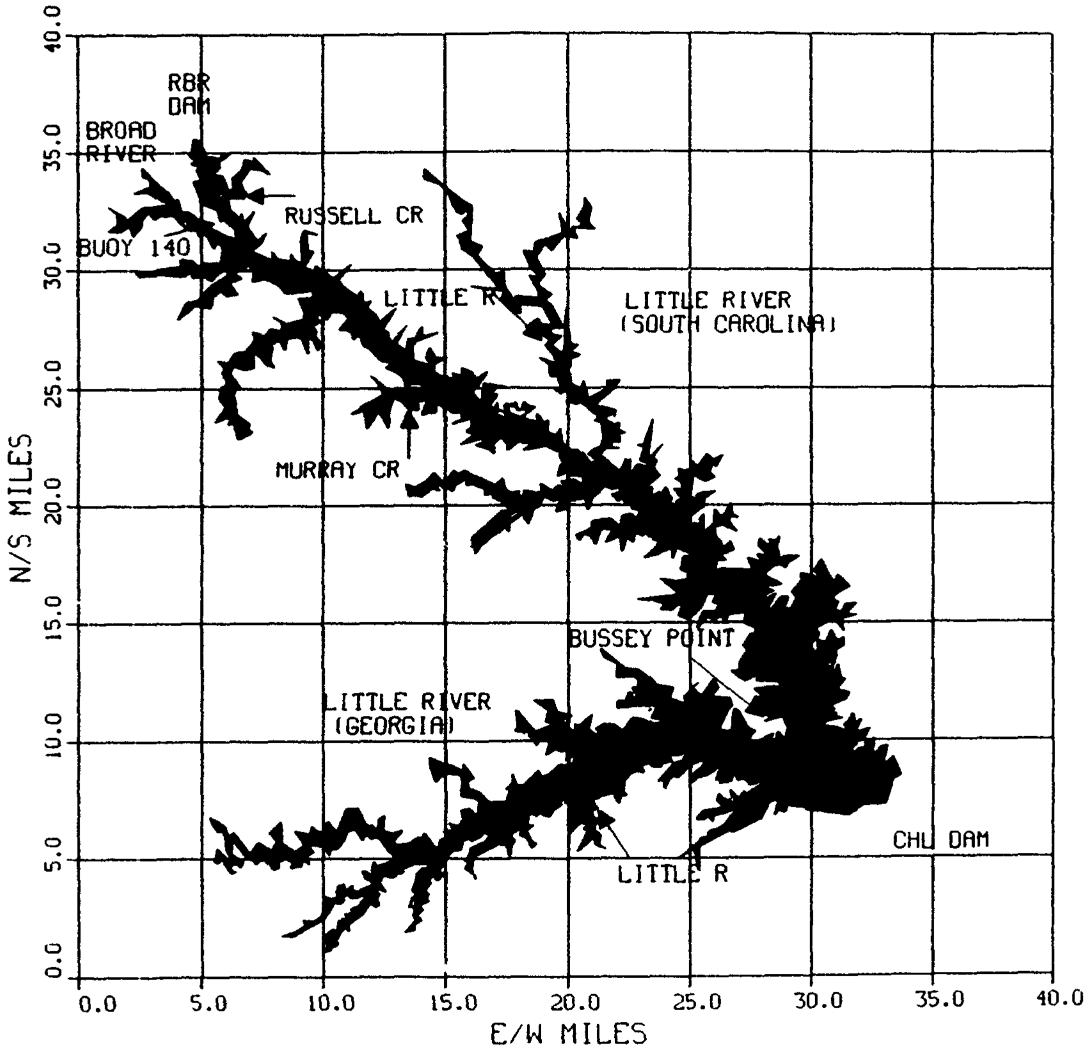
In August 1986, the Georgia Cooperative Fish and Wildlife Research Unit performed rotenone sampling at four coves on CHL (Figure 1). Two coves (Bobby Brown and Murry Creek) had been sampled previously by the Georgia Department of Natural Resources (DNR) and were, therefore, included on the basis of their historical significance as well as their proximity to RBR dam. Two additional coves (South Carolina Little River and Bussey Point) were sampled to provide a broader coverage of the reservoir. Two coves originally scheduled for sampling were not sampled either because of low water levels (Cliatt Creek) or concern that currents generated by generation at RBR dam would flush rotenone into open-water areas (Russell Creek cove). Specific cove rotenoning procedures used to collect the 1986 data were identical to procedures used by the Georgia DNR.

The purpose of this presentation is to summarize the results of rotenone sampling from four coves in CHL. The results provide baseline information on species composition and standing crop and an estimate of abundance in different parts of the lake.

Results and Discussion

Over one-half of the total biomass in all coves combined sampled (Figure 2) by rotenone consisted of four species: bluegills, gizzard shad, common carp, and largemouth bass. The cove at Buoy 140 (Figure 3) was the most diverse (26 species), followed by Murry Creek (24 species), Little River (22 species), and Bussey Point (20 species). Composition of fish assemblages differed considerably among coves. The most abundant species in the cove at Buoy 140 were common carp, flathead catfish, and bluegill. At Murry Creek, bluegill, redear sunfish, and common carp were predominant. The cove in Little River, S. C., contained high numbers of gizzard shad, river carpsuckers, bluegill, and threadfin shad. The most common species at Bussey Point were largemouth bass, bluegill, and yellow perch.

Historically, biomass levels at Buoy 140 and Murry Creek have been quite variable among years (Figure 4). The high biomass at Buoy 140 in 1986 may be due to two reasons. First, low water levels in 1986 probably increased the efficiency with which fish could be recovered. Second, the presence of a few large individuals of species such as common carp and flathead catfish in 1986 (Figure 5) caused a considerable increase in biomass. It is not known whether these increases are related to operation of RBR dam.



BUOY 140 - 375 KG/HA
AREA - 0.42 HA
MEAN Z - 2.07 M
MAX Z - 4.88 M

BUSSEY POINT - 132 KG/HA
AREA - 0.72 HA
MEAN Z - 1.71 M
MAX Z - 4.27 M

LITTLE RIVER SC - 425 KG/HA
AREA - 0.53 HA
MEAN Z - 3.00 M
MAX Z - 6.40 M

MURRAY CREEK - 196 KG/HA
AREA - 0.52 HA
MEAN Z - 2.47 M
MAX Z - 4.88 M

CHL MEAN - 282 KG/HA

Figure 1. Locations of rotenone coves of CHL and listing of summary results for each of the sampled coves. Note that only four of the six coves shown on the map were sampled in 1986

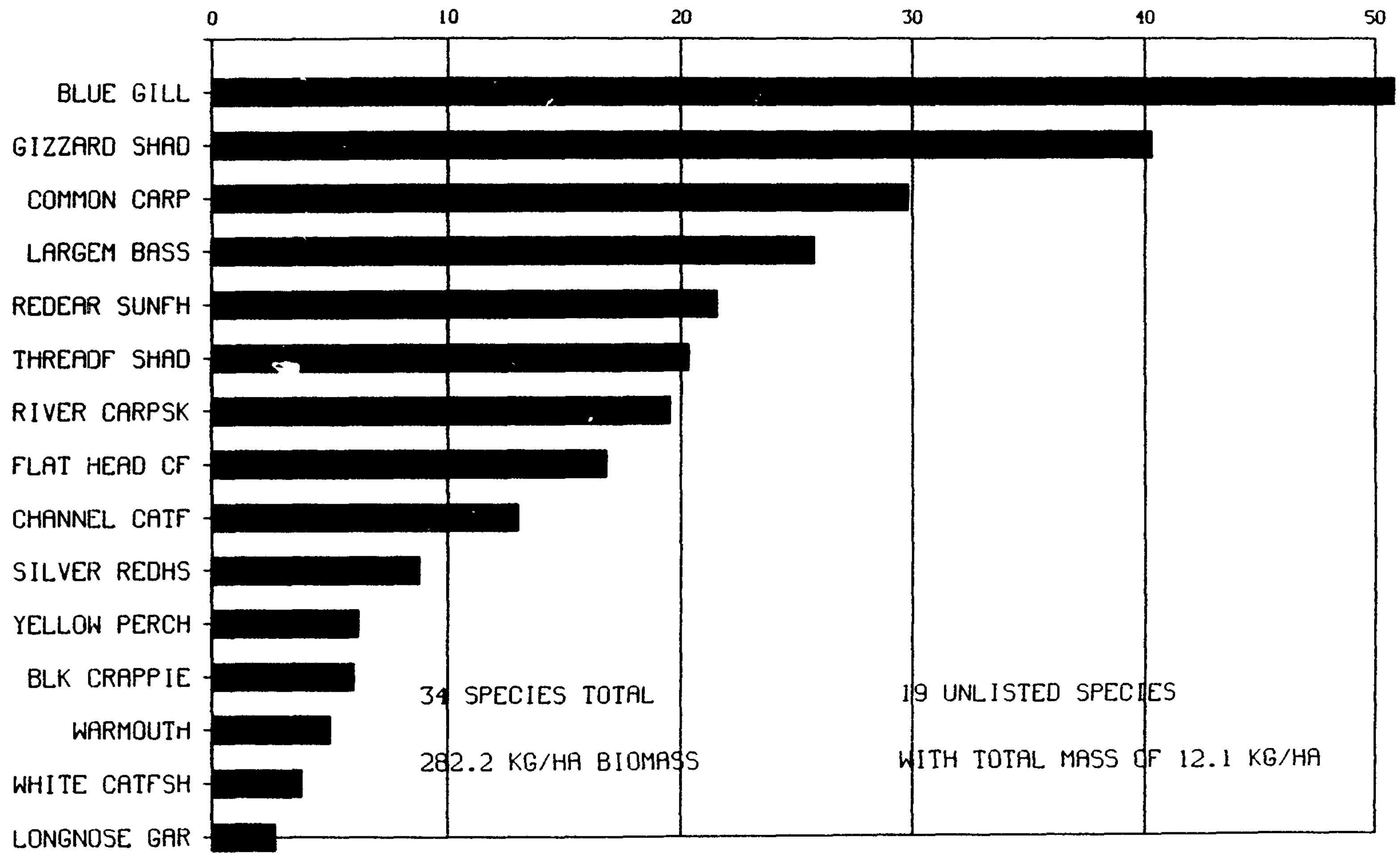


Figure 2. Summary of cove rotenone results (kilograms/hectare) for the 15 most abundant species in CHL. Results are presented for all coves combined. The 19 species that were captured, but not listed, had a combined density of 12.1 kg/ha

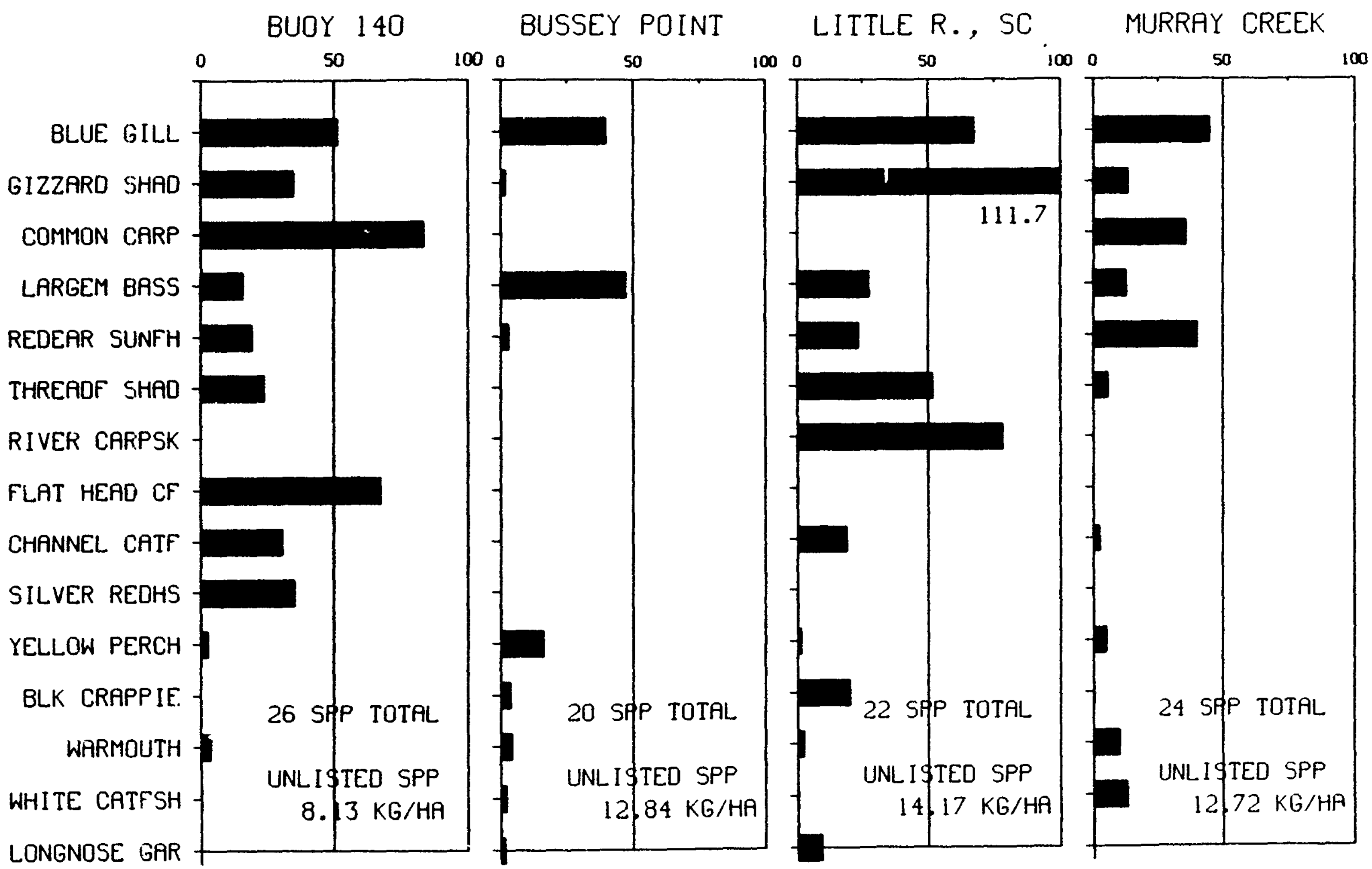


Figure 3. Results (kilograms/heccare) for the 15 most abundant species in CHL for each of the coves surveyed in 1986. Buoy 140 is located on the Savannah River arm of CHL, and Bussey Point and Murry Creek are coves located off of the main lake

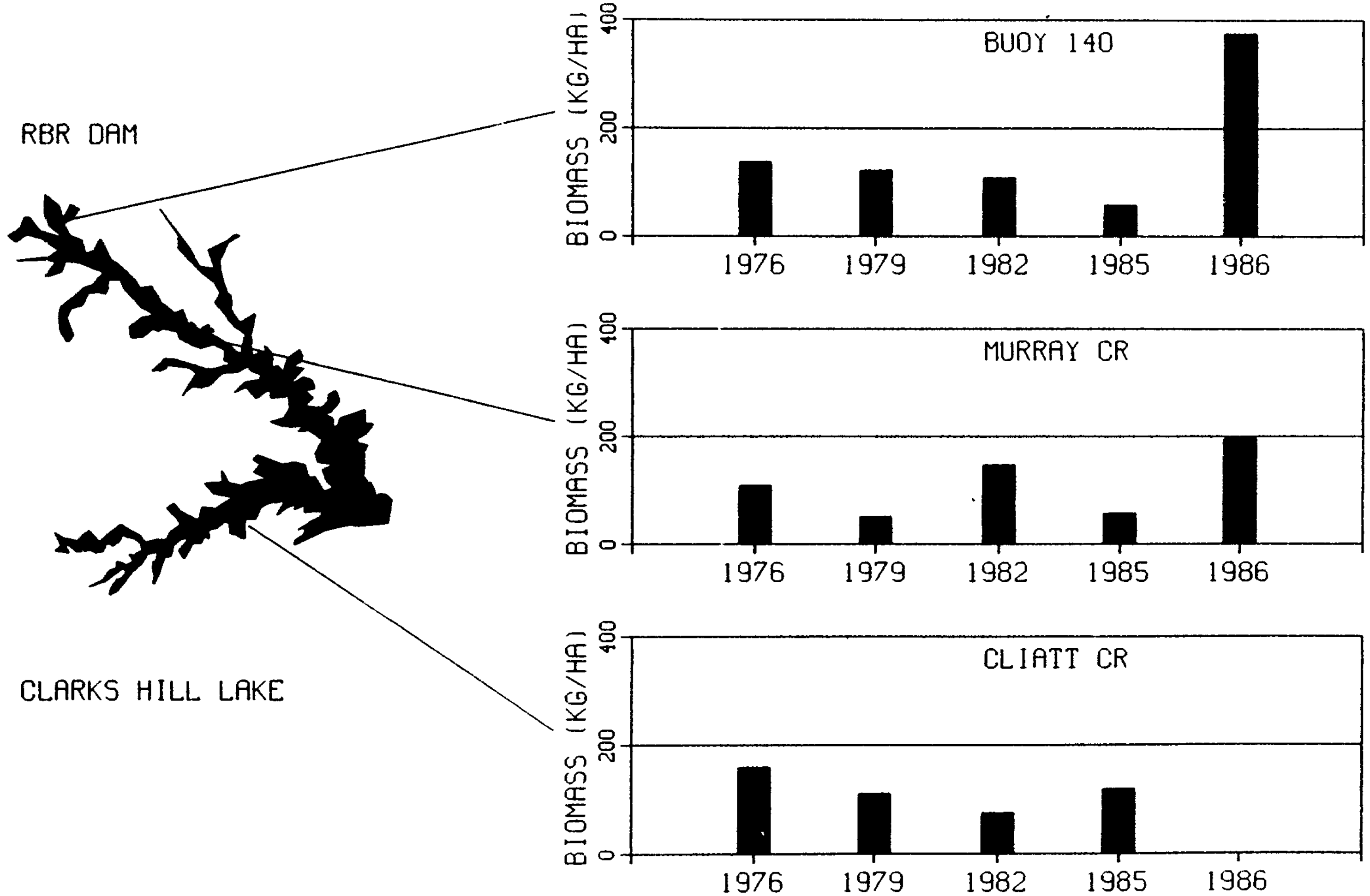


Figure 4. Historical trends for the Buoy 140, Murry Creek, and Cliatt Creek coves. Cliatt Creek was not sampled in 1986 because of low water levels. The Buoy 140 cove is located on the Savannah River arm of CHL. Note the large increase in standing stock in the Buoy 140 cove from 1985 to 1986

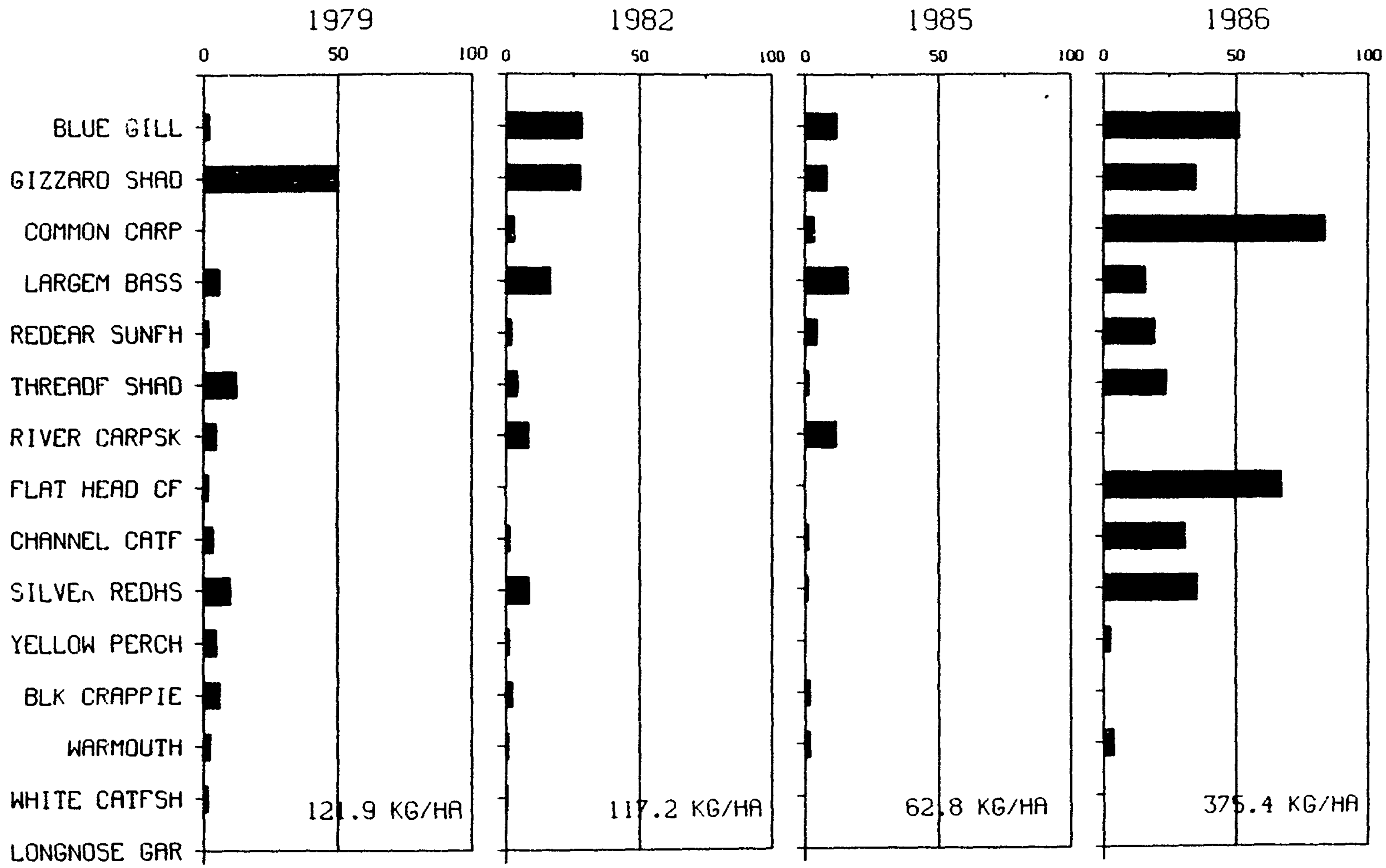


Figure 5. Relative species composition of the Buoy 140 cove (Savannah River arm of CHL) for 1979, 1982, 1985, and 1986. Note the high biomass of common carp, flathead catfish, and silver redhorse in 1986

CLARKS HILL FISH ENTRAINMENT STUDY: HYDRAULIC ANALYSES

Michael L. Schneider

US Army Engineer Waterways Experiment Station

Pertinent Features of the Project

RBR Dam was authorized on 7 November 1966 by the Flood Control Act of 1966 and provides power generation, incidental flood control, recreation, streamflow regulation, and water supply. The reservoir, situated between Hartwell and CHL, is the third major water control and recreational facility constructed on the Savannah River by the CE. The SAS is responsible for operating and maintaining the RBR project. The project currently includes a hydroelectric power plant consisting of four vertical-axis, fixed-blade Francis turbines rated at 75 MW each with a net head of 145 ft at maximum power pool and a total discharge of 30,000 cfs. The power output is used to meet the peaking power demands of the Southeastern Power Administration. The completed powerhouse will include an additional four 75-MW pump/turbine units with a rated generation capacity of 7,500 cfs, each yielding a maximum generation capacity of 60,000 cfs. Each of the four pump/turbines has a rated pumping capacity of 6,200 cfs for a combined pumping capacity of 24,800 cfs. Pumpback will occur during seasonally low-flow periods as needed.

Background

CHL has established an excellent fishery that is supplemented by stocking efforts. The CE monitors this fishery and is interested in minimizing any damage to this resource through the operation of the RBR Project. In the spring of 1982, the US Army Engineer District (USAED), Kansas City, initiated pumpback operations at the Harry S. Truman Dam that resulted in fishery impacts of sufficient magnitude to halt pumpback operations. The similarities in the design and operation of RBR Dam and Harry S. Truman Dam have given rise to concerns about the potential hazard to downstream fisheries upon the initiation of pumpback at RBR. These concerns have led to a detailed assessment of potential impacts on fisheries that might occur as a result of

proposed pumpback operations at the RBR project and to remedial measures for fish protection should adverse impacts occur.

Project Description

The RBR project consists of a powerhouse (625 ft wide) adjacent to the Georgia shore with a spillway section of about an equal width (600 ft). The width of the conventional turbine bays is 71 ft, while the pump/turbine bays are 9 ft wider (80 ft). The draft tube exits are divided into two equal halves by a structural pier with width and height dimensions of 29 by 19.3 ft and 25.5 by 19.4 ft, respectively, for the pump/turbines and conventional turbines. The invert of the draft tube is at elevation (el) 265 ft, enabling a 65-ft depth at normal tailwater pool (el 330 ft). The tailrace was constructed on a 1:5 slope for a distance of 175 ft downstream of the powerhouse and transitions into the natural headwaters of Clarks Hill Reservoir.

Purpose and Scope of Work

Many of the fish protection systems currently under consideration at RBR for the mitigation of fish entrainment during pumpback operation are located in the project's tailrace area. The success of these systems is largely dependent upon the velocity of the water in the region in which the entrance to the systems is located. Research (American Society of Civil Engineers 1982) has shown that many of these fish protection systems are most effective when entrance velocities are reduced to 1 to 2 fps. To properly locate and design these alternatives for maximum effectiveness, the anticipated hydrodynamic conditions during generation and pumpback are required. The hydrodynamic conditions during pumpback and generation can also aid in the determination of the head losses across the fish protection system. Some of the required hydraulic information can be gathered through field data collection. However, the flow field properties associated with pumped-storage operations cannot currently be measured in the field. To overcome this, a numerical model was employed to simulate the flow scenarios for the fully operational hydropower facility.

The approach taken for this study was to first assess the existing velocity fields associated with generation discharges through a field study.

Representatives of the WES Hydraulics Laboratory, with help from the SAS and the WES Environmental Laboratory, conducted a field investigation of the velocity fields associated with generation discharges from RBR Dam. This field study concentrated on describing the far field depth-averaged tailwater velocities and the near field velocity patterns in the tailrace of RBR Dam.

The second phase of this study involved the use of field observations to develop a numerical model of the afterbay region of RBR for the prediction of hydraulic conditions at the completion of the project for maximum generation and pumpback. Flow conditions during full conventional generation (60,000 cfs) and full pumpback (24,800 cfs) at normal (330 ft) and minimum (312 ft) tailwater pool elevations were modeled for the existing powerhouse design. A two-dimensional steady-state hydrodynamic model using boundary-fitted coordinates was selected for modeling these flow conditions. This model solves either the depth or width-averaged equations of motion subject to prescribed boundary conditions. The laterally averaged equations of motion more closely approximated the flow conditions at the mouth of an interior draft tube section. Flow conditions in the tailrace, significantly removed from the mouth of the draft tube, were more closely approximated by the depth-averaged equations of motion. Results from both of these calculations were used to characterize the four flow conditions simulated.

Field Study Investigation

Depth-averaged steady-state velocities for a high- and low-flow event were monitored on four cross sections in the afterbay regions of RBR using a Price current meter. Four cross sections were identified normal to the direction of flow for monitoring purposes. These transects were located downstream of major changes in the channel cross section. Station markers were located at equal distances across each transect to establish monitoring stations. Constant hydropower releases were requested from SAS during the period of this study.

The flow patterns observed during this investigation indicated a shifting of flow distribution from transect to transect. Transect A indicated flow directed downstream along the Georgia bank and return flow directed toward the dam on the South Carolina bank (Figure 1). The predominant conveyance of flow shifted toward the South Carolina side of the channel at Transect B due to the

remains of a cofferdam adjacent to the Georgia bank. The major component of flow moved back to the Georgia side of Clarks Hill by the third velocity transect. This flow movement was caused by a shallow shoaling area located predominantly in South Carolina. Velocities were significantly reduced on Transect D due to the abrupt expansion in the channel with the velocities skewed toward the Georgia bank.

The hydraulic characteristics associated with generation flows in the near field tailrace region of RBR focused on the three-dimensional flow characteristics from a single hydropower turbine (Unit 2). Four velocity transects were identified directly downstream from Unit 2. Three stations were located on each transect to monitor the lateral variation in flow field properties. The power output from Unit 2 was coordinated with SAS personnel stationed at RBR Dam. The other units were operated to meet the hourly power demands requested from the project. The monitoring vessel was anchored on station, and velocity information was gathered at 5-ft depth increments starting at the surface. The velocity magnitude and the direction of flow were monitored over a time period of 1 min.

Alternating high and low velocity regions were observed in the tailrace (Figure 2). Velocities observed were highly variable both spatially and temporally for all flow conditions monitored. The generation releases observed at the draft tube exit were consistently skewed toward the Georgia side of the project with up to 70 percent of the flow exiting from this half of the draft tube. The major component of flow exited approximately 15 deg from normal to the face of the powerhouse. This flow feature seemed to be present from the other units not monitored in this study as evidenced by surface disturbance properties. The maximum averaged velocity monitored in the tailrace was 8.0 ft/sec at 70-MW generation. Instantaneous velocities periodically registered in excess of 20 ft/sec indicating the high degree of turbulence present in this region. A return surface current was monitored near the powerhouse indicating a low velocity recirculation cell generated from the release jet.

Numerical Model

A computer code entitled STREMR has been developed for determining the steady-state velocity and pressure fields of flow near hydraulic structures

(Bernard 1985). STREMR solves the two-dimensional Navier-Stokes equations in stream-function/vorticity form through finite difference approximation. The code is applicable to flow fields in two dimensions represented in either a plan or profile view. Both laterally and depth-averaged simulations were conducted to describe the generation and pumpback flow characteristics. These results must be interpreted in light of the temporal and spatial averaging of flow field properties that are inherent to the model formulation.

Depth-Averaged Model Application

The two-dimensional flow patterns associated with generation and pumpback were simulated assuming depth-averaged conditions. The field study observations suggested that depth-averaged conditions applied over much of the tailrace region during generation. For generation simulations, the numerical model results were found to apply for regions greater than 200 ft downstream from the powerhouse. Flow conditions during capacity pumpback are expected to closely approximate depth-averaged conditions since flow separation is not expected to occur. These conditions should apply up to 50 ft from the project, where significant vertical flow acceleration is anticipated.

A numerical grid covering the bank-to-bank afterbay region of RBR from the draft tube conduits up to 1,500 ft downstream was developed assuming the powerhouse to be completed as proposed (without fish control systems). Hydrographic survey information provided by the SAS was used in determining the bathymetric features across the grid. The prominent topographic features in this region included the sloping tailrace, the shallow shelf downstream of the spillway section, and the shallow region associated with a sandbar on the southeastern end of the grid.

Model Results: Depth-Averaged

The observed flow conditions monitored during the field investigation were simulated by the numerical model with the intent of selecting model coefficients that best reproduced the observed flow patterns at the buoy line. The best agreement of the numerical model results with the observed field data occurred with the turbulent eddy viscosity coefficient equal to zero and the Manning's "n" coefficient equal to 0.02.

The maximum generation flow of 60,000 cfs was simulated for normal tailwater conditions (el 330 ft) assuming a uniform discharge across the powerhouse. The eddy that developed downstream of the spillway prevented the rapid dissipation of the release flow, as shown in Figure 3. Flows from Units 1-6 are generally directed normal to the powerhouse in the tailrace region. These flow features were incorporated into the laterally averaged simulations of generation flow by assuming a constant flow width throughout the tailrace region.

The maximum pumpback flow of 24,000 cfs was modeled for normal pool conditions by assuming a uniform distribution of flow across the intakes to the pump/turbine Units 5-8. The resultant velocity vectors indicated asymmetric approach flow conditions, as illustrated in Figure 4. The flow approaching Unit 8 exhibited much stronger crosscurrents than the flow approaching Unit 5. This approach flow condition may lead to a smaller pumping efficiency for Unit 8 as compared with the other units due to undesirable entrance flow conditions. The asymmetric approach flow conditions for Unit 8 were brought about by the shallower depths of flow in front of the spillway section. The convergence of streamlines is much more apparent in the simulation of pumpback capacity flow. For flow approaching interior pumping Units 6 and 7, the width of corresponding flow lines is reduced in half over the final 400 ft of approach to the project. This rate of convergence was used in the laterally averaged model applications of pumpback flow conditions. The effects of no flow adjacent to pump/turbine 5 should cause the approach velocities to be smaller on average than those associated with Units 6 and 7. The same cannot be said of Unit 8 because of the potential for flow separation. This condition would reduce the effective conveyance area at the draft tube entrance while increasing the approach velocities.

Laterally Averaged Model Application

Of primary concern in this study were the hydraulic characteristics associated with the proposed pump/turbines. It was initially assumed that the hydraulic conditions during generation for the existing turbines would be similar to the characteristics of the proposed pump/turbines. The validity of this assumption will depend upon the complex hydrodynamics of the pump/turbine and adjoining draft tube. A goal for most pump or turbine designs is to

minimize energy losses by providing uniform inflow and outflow conditions. The numerical model simulated these ideal inflow and outflow conditions rather than the three-dimensional conditions observed for the existing turbines. If release discharges from the pump/turbine prove to be highly asymmetric, the maximum velocity could be significantly larger than those modeled in this study.

A numerical mesh of the RBR tailrace was developed for both normal (el 300 ft) and minimum tailwater pool (el 312 ft) conditions. The laterally averaged numerical model calculations were performed on a 41 by 21 grid that reproduced the profile-view geometry in the tailrace. A flow domain width of one pump/turbine bay width was used for the entire flow domain for generation flows. The widths applied during pumpback flow conditions varied linearly from one pump/turbine bay width at the entrance of the draft tube to two pump/turbine bay widths on the opposite end of the mesh.

As a part of the STREMR application overviewed above, the numerical model was adjusted through the observations made during the field studies based on comparisons of the predicted and observed surfacing of the discharge jet. The variability in the observed discharge jet properties was best represented in the model by an upper and lower bound of turbulent eddy viscosity coefficients (1.77 m^2/sec and 1.36 m^2/sec). Generation flow simulation proved to be highly sensitive to this coefficient.

The maximum generation flow for the pump/turbine units was simulated for normal tailwater pool conditions assuming a uniform discharge of 7,500 cfs across the pump/turbine bay. The lower bound turbulent eddy viscosity coefficient resulted in higher velocities in the tailrace region and is shown in Figure 5. The discharge jet diffused in the vertical direction upon exit from the draft tube. A secondary current (or eddy) driven by the release jet developed at the shallower depths adjacent to the face of the powerhouse. As flow moved downstream, the velocities decelerated at a rate dependent upon the extent of the recirculating eddy. The maximum velocity, however, remained near the floor of the tailrace until the uniform natural channel was reached 175 ft downstream from the draft tube exit. Velocities exceeded 2 ft/sec throughout this region with the exception of recirculation velocities. Velocities greater than 5 ft/sec can generally be expected to be found up to 60 ft downstream from the powerhouse.

The maximum generation at minimum pool resulted in velocity conditions that became significantly different from normal pool conditions with increasing distance from the powerhouse. The same large-scale flow features were present for maximum generation at minimum pool near the draft tube exit, as shown in Figure 6. However, the discharge jet diverged at a faster rate than at normal pool conditions because of the relatively weaker roller that developed above the discharge jet. This translated into smaller velocities within 50 ft of the project for minimum pool conditions as compared with normal pool conditions. The minimum pool elevation resulted in releases surfacing about one-half the distance of those observed at normal pool. The flow began to accelerate on the downstream half of the sloping tailrace section. The average velocity in the discharge jet did not fall much below 4 ft/sec throughout the tailrace region.

The worst-case scenario of pumpback flow was modeled for normal tailwater pool conditions by assuming an approach flow of 24,800 cfs distributed uniformly across Units 5-8. Pumpback flows less than capacity should result in smaller approach flow velocities. The following results apply strictly to the approach flow conditions to Units 6 and 7 since a flow-specific convergence rate, as determined in the depth-averaged simulations, was assumed. The highly three-dimensional flow characteristics in the approach to Units 5 and 8 prevent a similar type of analysis. It is anticipated that approach velocities to Unit 5 will be slightly less than those simulated for Units 6 and 7. The approach flow conditions to Unit 8 should be equal to or greater than approach flow conditions to the interior units because of the potential for flow separation. If the flow distribution is highly asymmetric at the draft tube entrance, local approach velocities will be larger than those generated in this study. It is also anticipated that the inlet conditions will be closer to uniformity during pumpback operation than during generation.

The calculated capacity pumpback streamlines are close to inviscid flow conditions as shown in Figure 7 for normal tailwater conditions. As the flow transitioned from the natural channel section to the sloping tailrace section, the velocities decreased gradually. This deceleration continued until flow lines were turned at the face of the powerhouse. From this point, the flow quickly accelerated into the draft tube entrance. Velocity exceeding 2 ft/sec can be expected within 30 ft of the draft tube entrance. It is expected that the amount of turbulence will be significantly less during pumpback flows than

generation flows because of the direction of flow relative to the major turbulence generating features (pump/turbine). Simulations of laterally averaged capacity pumpback with significantly smaller turbulent eddy viscosity coefficients did not change the resultant streamlines appreciably.

The capacity pumpback flow was also modeled for minimum pool conditions with the general result of much higher approach velocities than normal pool conditions. The approach velocity was quickly reduced from over 5 ft/sec along the natural channel to 2 ft/sec midway through the tailrace region (Figure 8). Significant acceleration of the flow occurred near the entrance of the draft tube. The magnitude of approach velocities exceeded 2 ft/sec over much of the tailrace region. The results indicated that approach velocities exceeding 2 ft/sec will occur up to 40 ft from the entrance to the draft tube. Significant asymmetry in the entrance conditions would lead to regions of flow exceeding 2 fps throughout the tailrace area.

Conclusions

The flow patterns observed in the field study of generation flows from RBR Dam were highly variable due to the turbulence in the tailrace region. The dissipation of the discharge jet was measured at several distances downstream from the draft tube exit with velocities exceeding 6 ft/sec as far as 100 ft away from the project. A return surface current was observed on several transects, which indicated the presence of an eddy located above the elevation of the draft tube exits. The lateral flow distribution at the draft tube exit was highly asymmetric for a wide range of flow conditions. For Unit 2, about 60 percent of the discharge was released from the Georgia side of the draft tube. A similar flow distribution was observed 100 ft downstream from the powerhouse indicating the existence of low velocity corridors during generation flows. The release characteristics for the other units appear to be similar to those measured downstream from Unit 2 judging from the water surface disturbances.

The flow conditions for capacity generation and pumpback were simulated with a numerical model for normal and minimum pool conditions for depth- and width-averaged conditions. The steady-state width-averaged velocities during capacity generation exceeded 2 ft/sec throughout most of the tailrace region. If significant flow asymmetry is present in these releases, the maximum

steady-state tailrace velocities will be much larger than calculated. The approach flow velocities during capacity pumpback for interiorly located pump/turbine units exceeded 2 ft/sec within 30 ft of the project under normal pool conditions. Minimum tailwater pool conditions resulted in velocities exceeding 2 ft/sec up to 40 ft from the project. The simulated flow fields were all conducted assuming no structural modifications to the proposed powerhouse. The properties associated with capacity generation and pumpback may change significantly if such a structure is added to the project.

References

American Society of Civil Engineers. 1982. "Design of Water Intake Structures for Fish Protection," New York, N. Y.

Bernard, R. S. 1985. "STREMR--User's Manual," Draft Technical Report, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

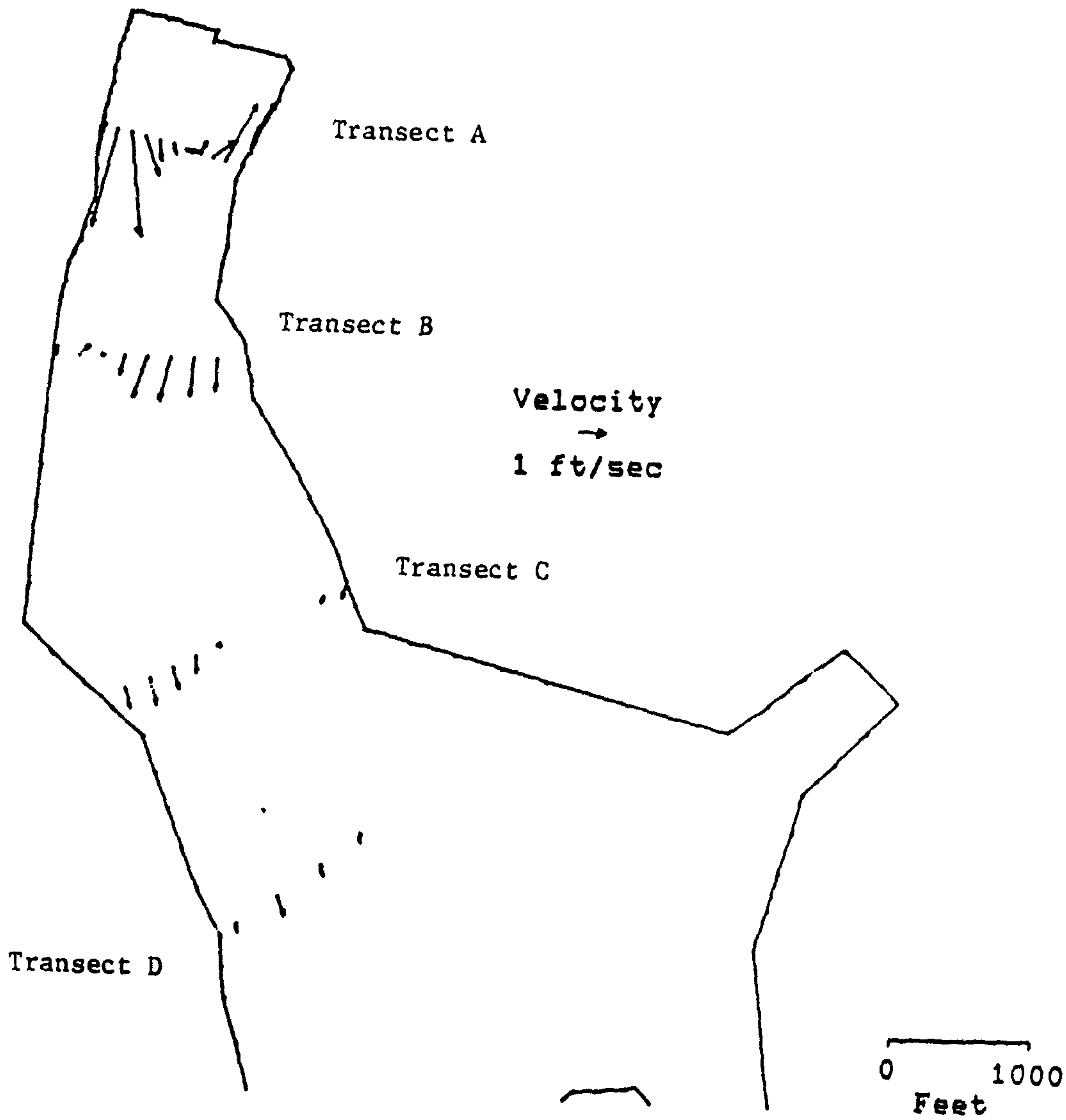


Figure 1. Depth-averaged velocity patterns for generation flow (Q = 8,925 cfs)

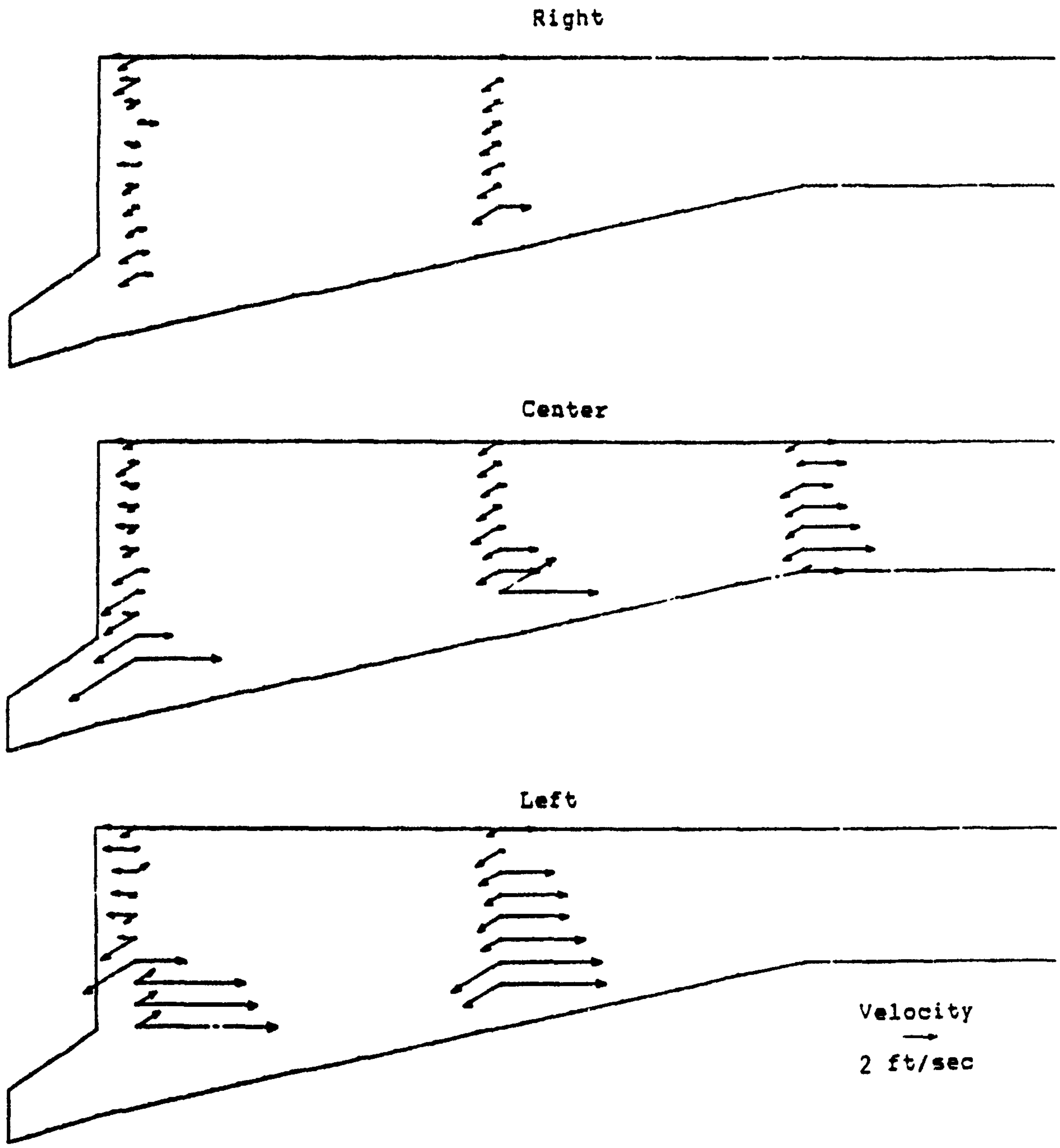


Figure 2. Tailrace velocity patterns for generation flow from Unit 2 (Q = 5,050 cfs)

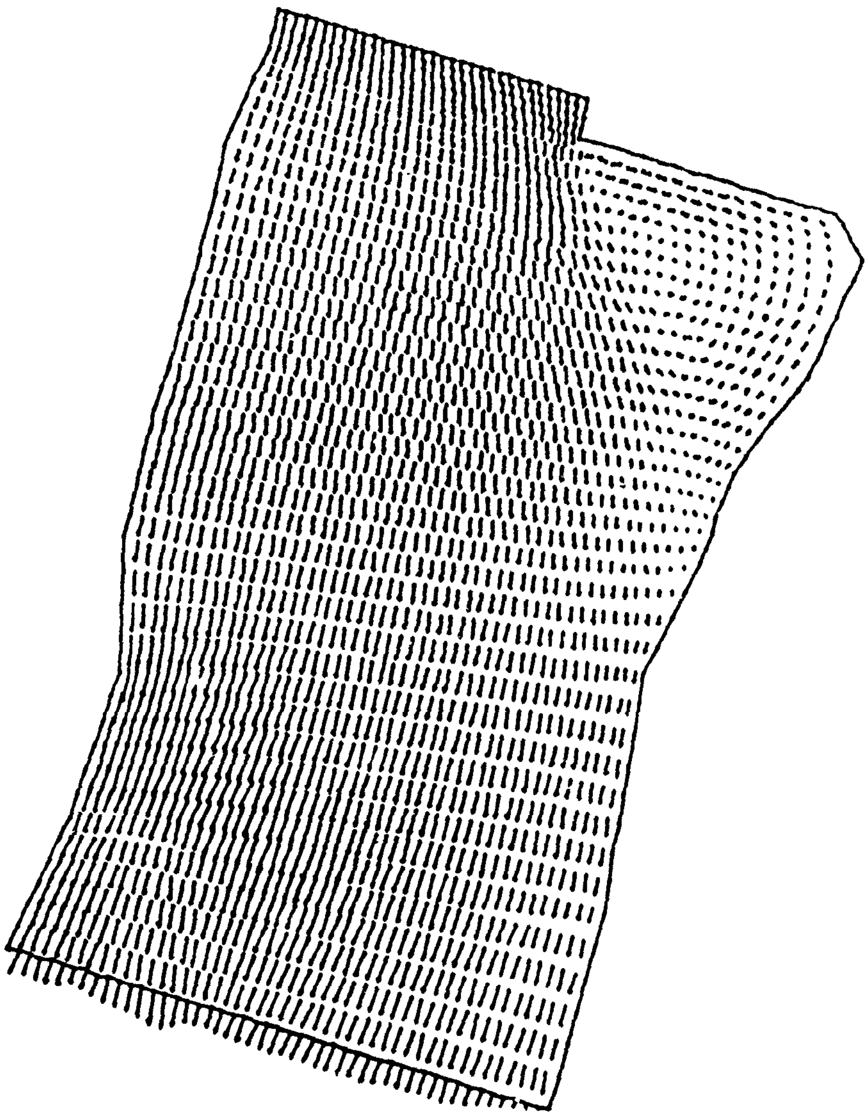


Figure 3. Velocity vectors for capacity generation at normal pool (el 330)

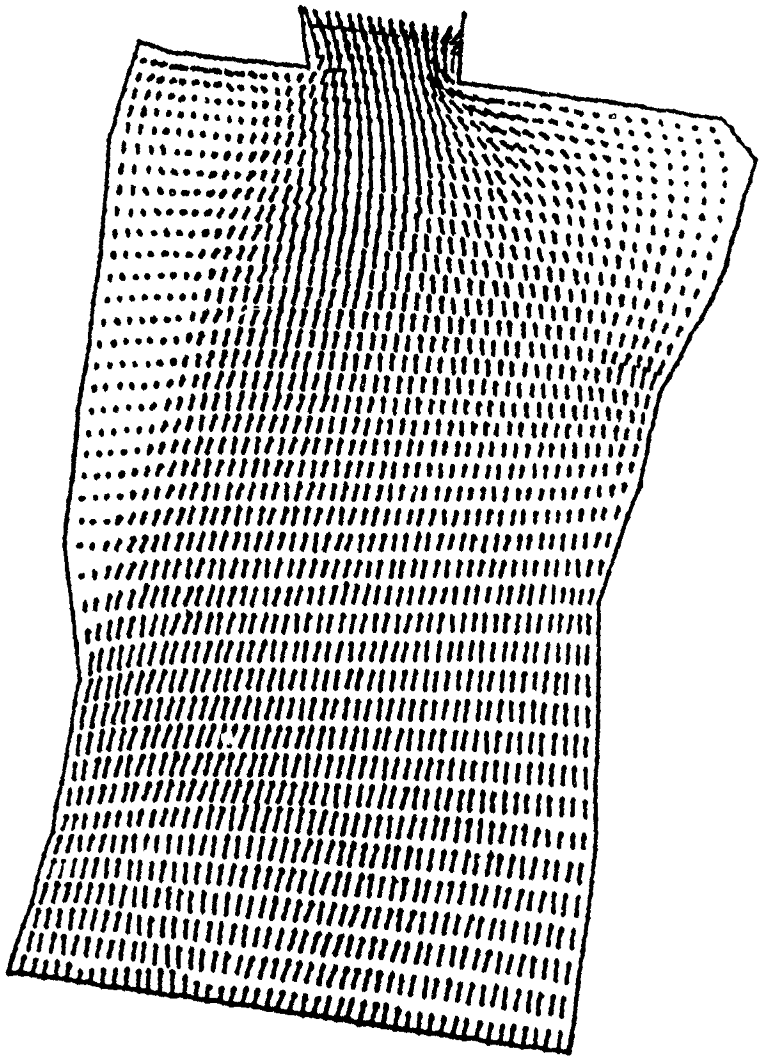


Figure 4. Velocity vectors for capacity pumpback at normal pool (el 330)

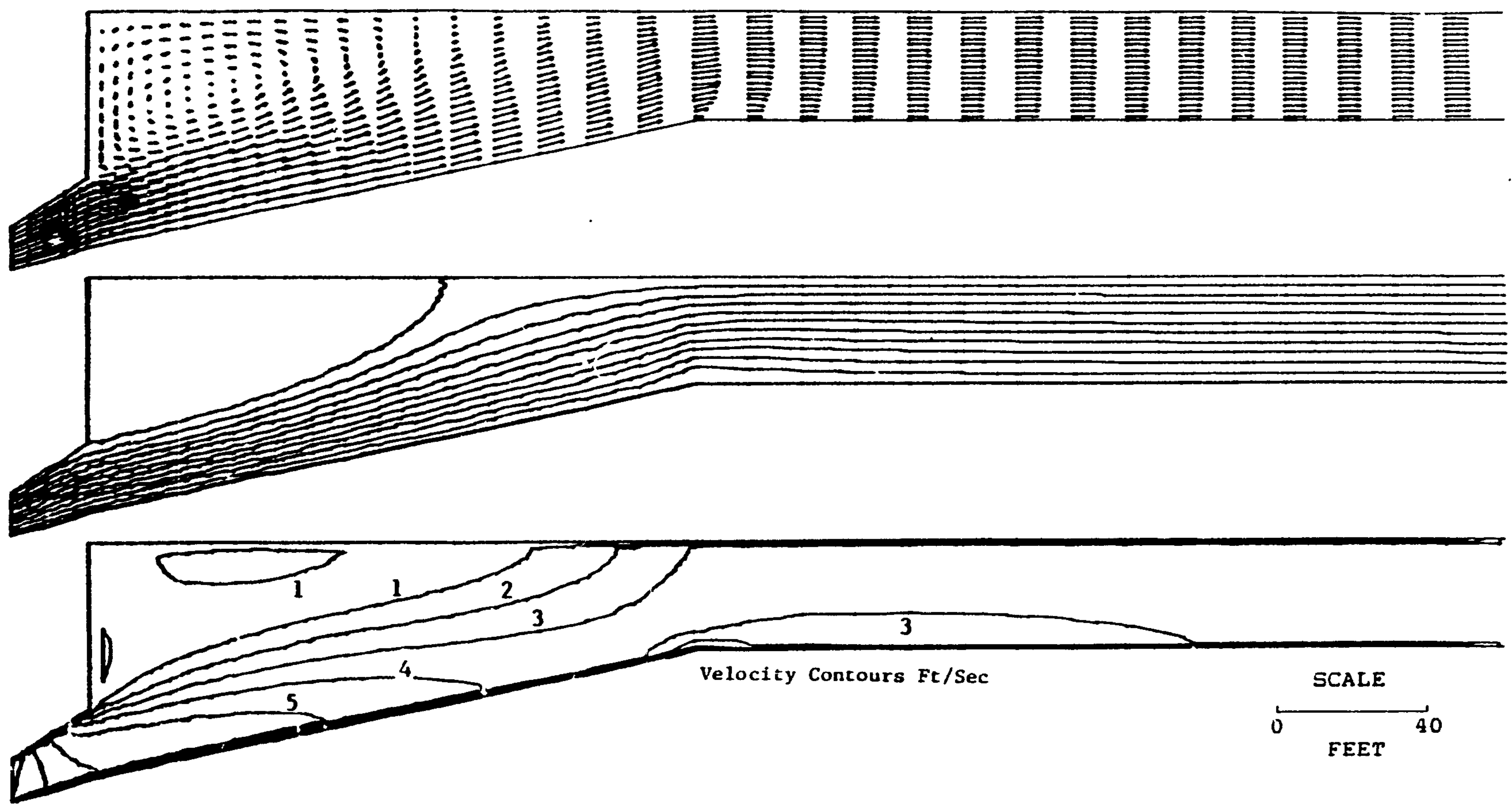


Figure 5. Velocity vectors, streamlines, and velocity contours for capacity generation at normal pool (E_t = 1.36 m^2/sec)

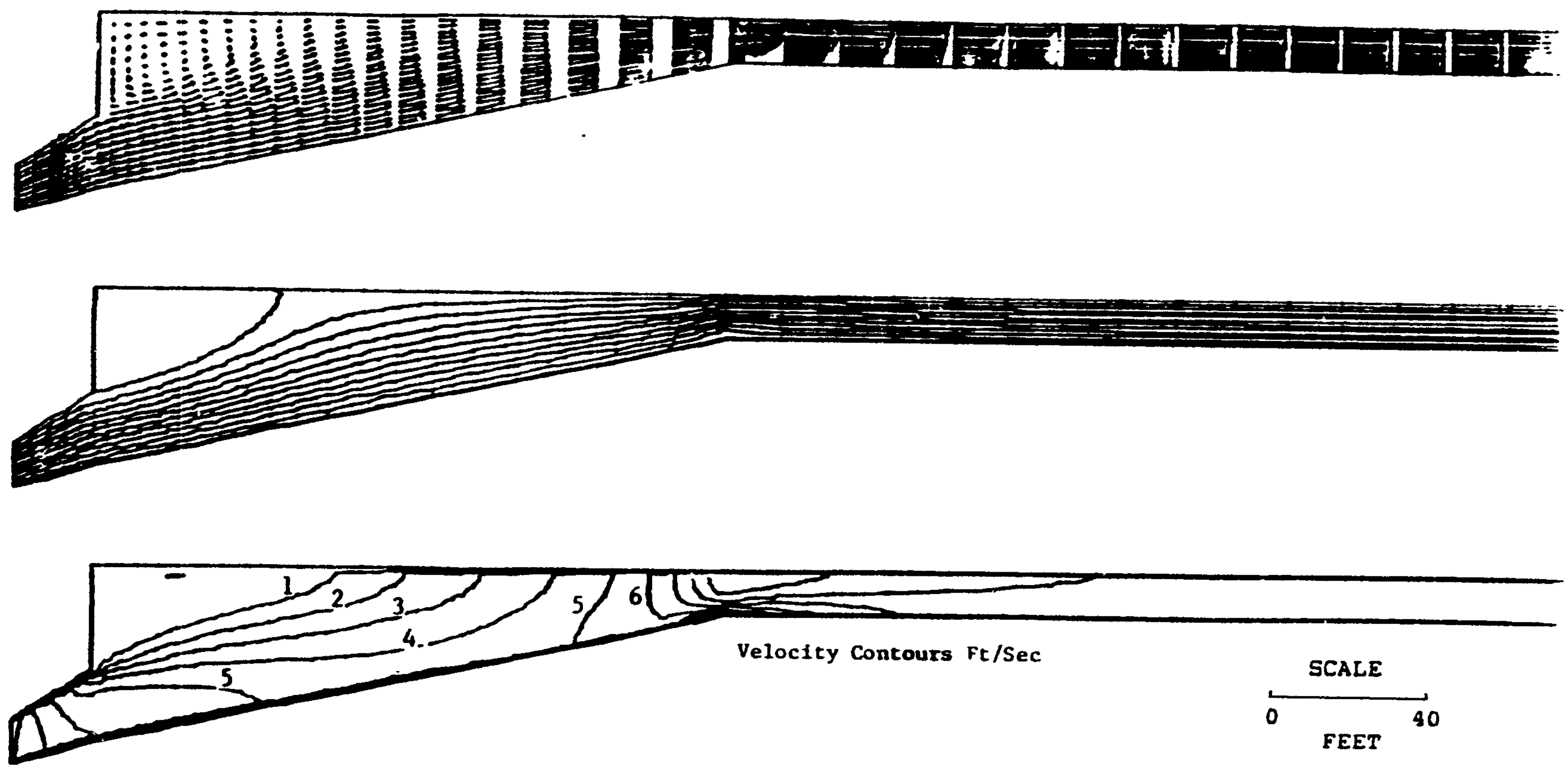


Figure 6. Velocity vectors, streamlines, and velocity contours for capacity generation at minimum pool (E_t = 1.36 m^2/sec)

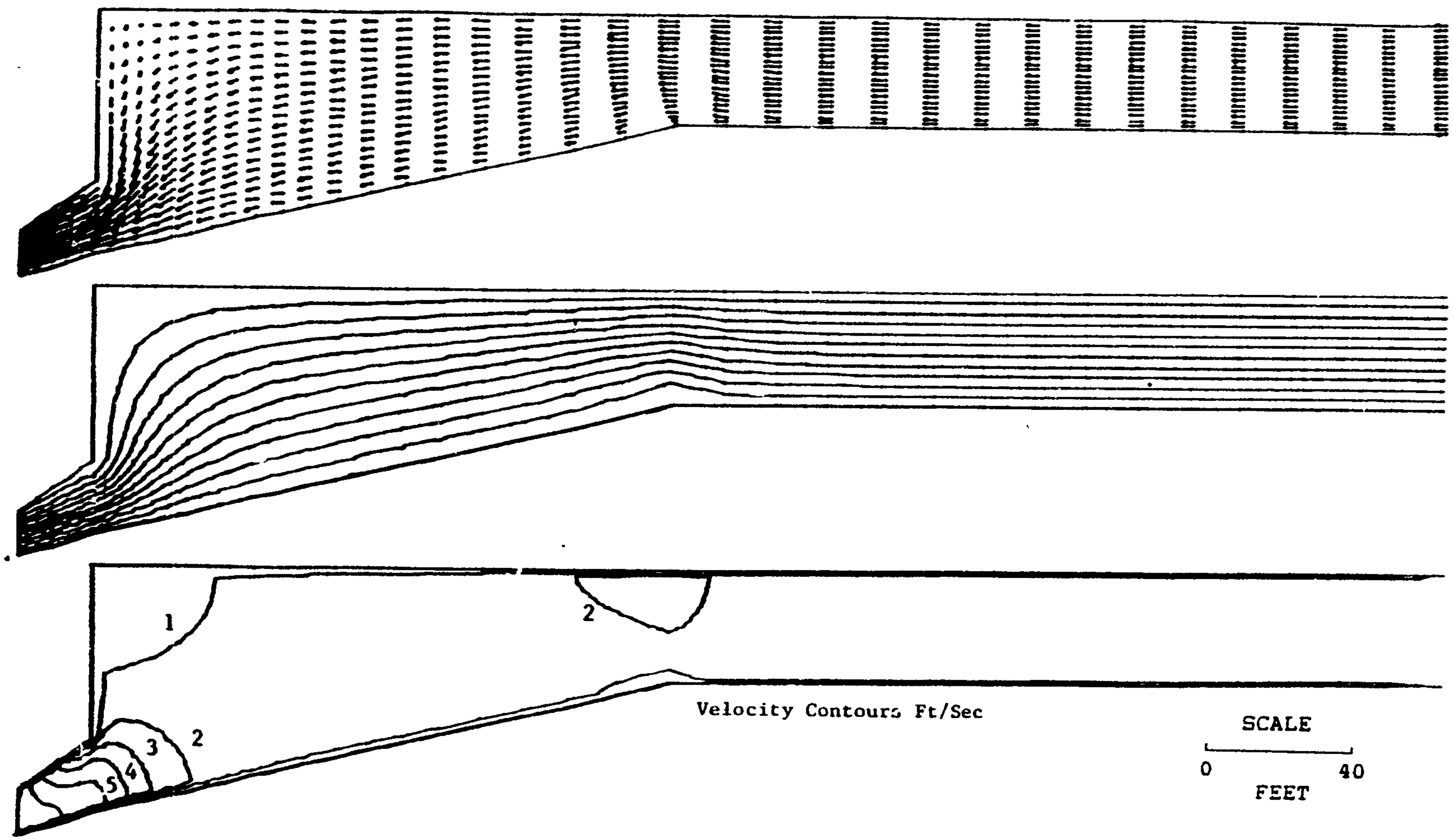


Figure 7. Velocity vectors, streamlines, and velocity contours for capacity pumpback at normal pool (F_t = 1.77 m^2/sec)

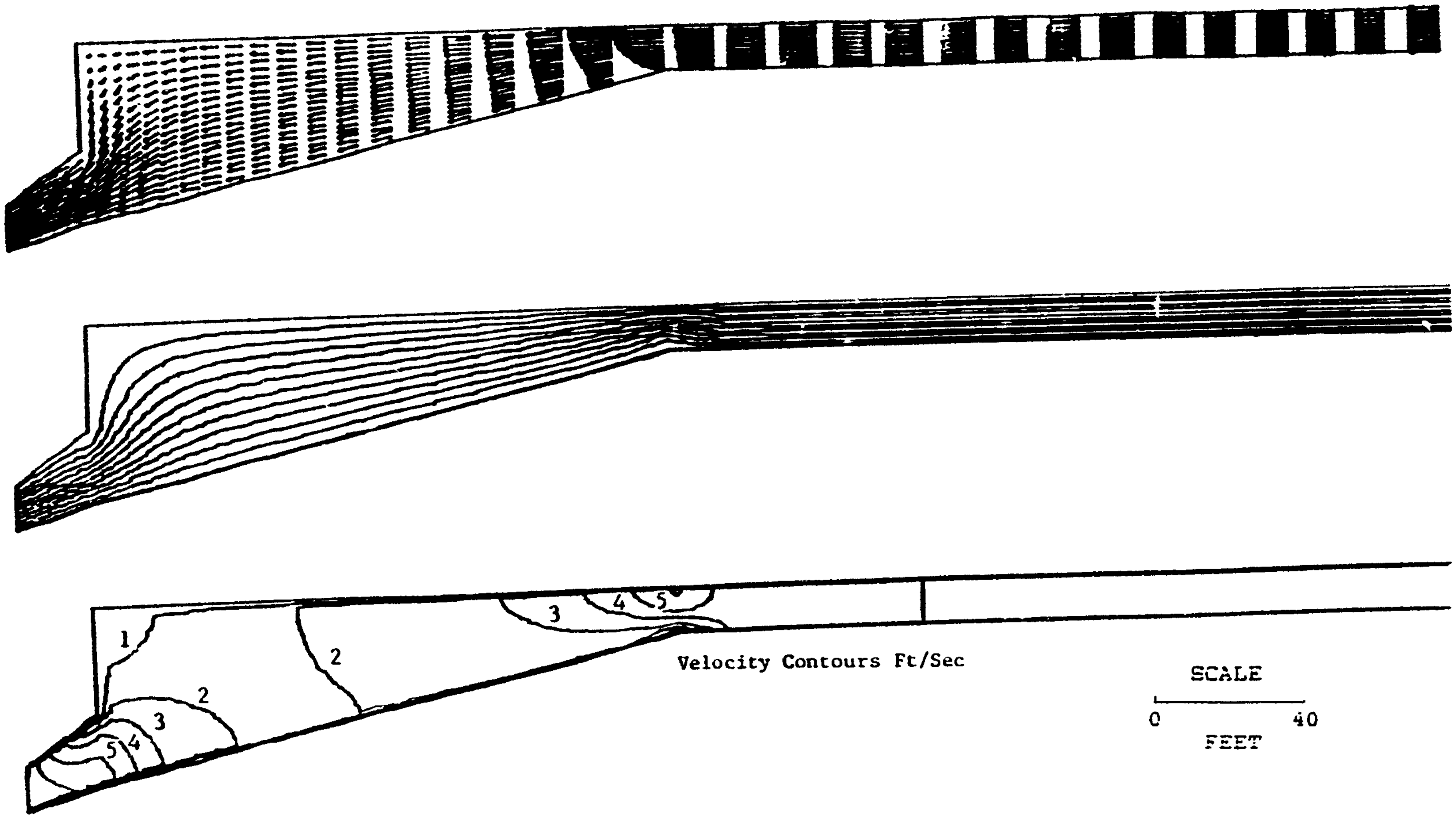


Figure 8. Velocity vectors, streamlines, and velocity contours for capacity pumpback at minimum pool (E_t = 1.77 m^2/sec)

Table 1

Target Strength (TS) Summary Statistics

Month	Stations	Medians TS	Percent <7 in. (-41 dB)	Percent >23 in. (-31 dB)
Jul	Tributaries	-50	78	2.3
	Main Lake	-56	87	3.2
	Russell Dam	-52	87	0.5
	Russell Tailwater	-50	86	0.1
Sep	Tributaries	-52	90	0.0
	Main Lake	-54	95	0.0
	Russell Dam	-54	96	0.0
	Russell Tailwater	-54	94	0.5

PRELIMINARY RESULTS FROM CLARKS HILL LAKE HYDROACOUSTIC SAMPLING

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Introduction

Hydroacoustics involves the use of sonar systems to obtain information about underwater objects and activities. Short pulses of ultrasound are produced by echosounders and transmitted through the water until they strike an object that has a density different from water, and part of the wave is reflected back to the echosounder. By measuring the intensity of the reflected echo, its position in the acoustic beam, and the time it takes for the echo to return to the echosounder, it is possible to make quantitative estimates of fish size, distribution, and abundance.

Recent advances in hydroacoustic equipment and techniques have established this technology as an important addition to available fishery sampling techniques (Acker et al. 1975, Thorne 1977, Traynor and Eherenberg 1979). Acoustics has become particularly useful where traditional techniques are difficult to use and precise quantitative estimates are required. In most cases, a combination of hydroacoustics and traditional sampling provides the best means of obtaining required information. Both of these methods are being used in the RBR fishery study.

Hydroacoustics has several advantages over traditional fish sampling techniques. To begin with, hydroacoustic techniques are nondestructive and

noninvasive, neither destroying the sampled fish nor disturbing the environment. Surveys can be conducted at high speed and over long transects, providing better spatial coverage. Quantitative estimates of fish biomass can be obtained that are as good or superior to more traditional methods such as catch per unit effort. Multiple-depth intervals and target sizes can be sampled simultaneously, and it is easier to sample deep, swift, turbid mainstream areas where depth and current preclude traditional sampling techniques. Net avoidance problems, which are common in traditional net sampling, are avoided using acoustics. Behavioral observations, such as diurnal migrations in and around man-made structures, can be made. In many instances, it may be possible to reduce overall survey costs by increasing efficiency. This can be accomplished with lower manpower requirements and improved coverage. Finally, statistical interpretation of results and comparison of data are improved by the acquisition of large quantitative data bases and increased sample sizes.

There are limitations to hydroacoustics. The most serious is the inability to identify fish species. Species identification can only be indirectly inferred unless supplemented by traditional sampling methods. Specialized equipment is needed, and the initial costs associated with acquiring this equipment are relatively high. Additionally, specialized training is required to collect and process data. Formalized training at academic institutions and educational materials (texts) are lacking at this time; consequently, most biologists have only a limited knowledge of acoustic principles and applications. Another shortcoming of some acoustic systems is the inability to accurately calculate fish target strength, which is essential for echo integration and calculation of relative fish biomass.

This problem has been overcome with the development and use of dual-beam transducer systems, such as the one used in this study. Dual-beam systems allow for accurate calculation of target strengths and subsequent calculations of fish density.

Hydroacoustic surveys can be designed in a variety of ways depending on project objectives. Transducers can be deployed in a "fixed" mode, transmitting data on fish presence and behavior, or they can be towed by a vessel in "mobile" surveys thereby covering large areas to obtain information on abundance and distribution. Transducers can also be employed in remote sites and data transmitted to a receiver at a different location. Data processing can be accomplished in real-time if required, or data can be stored on videocassette tapes for subsequent processing. The latter option was chosen at CHL due to the enormous amount of data to be collected and the analysis required.

A typical hydroacoustic system consists of a transmitter and receiver, usually housed in the same container and called a transceiver or echosounder. The transmitter produces an electronic signal at timed intervals that travels to the transducer. The transducer converts the signal to acoustical energy and radiates this energy through the water in a specific cone-shaped pattern. Reflected acoustical energy is converted to electrical energy by the transducer and then is timed, amplified, and filtered by the receiver. Display devices such as paper chart recorders and oscilloscopes are used to monitor the received signals and provide a hard copy record for visual reference. Videocassette recorders are used to tape the signal for future reference and processing on electronic processing equipment. Microcomputers

and appropriate software aid in data processing and analysis. The specific equipment used in this study will be discussed in the methods section of this report.

Scientific grade hydroacoustic equipment is only superficially similar to commercial equipment. Scientific grade equipment is finely calibrated, of high resolution, and stable, allowing acquisition of several kinds of information about acoustic properties of targets. The characteristics of scientific equipment are well defined, well controlled, and repeatable between surveys (Kanciruk and Pennington 1985).

Hydroacoustic Surveys

Objectives

Acoustic data were used to estimate the abundance, size, and spatial distribution of fishes. These data complemented other fishery data collected from the same locations and also provided data that were unavailable using other fish sampling methods. Acoustic sampling was conducted pursuant to two general objectives: (a) to assess the magnitude of the fishery in the project area relative to other areas of CHL and (b) to evaluate seasonally and operationally related patterns of fish abundance and distribution in the near-project area, the latter for the purpose of assessing whether a potential exists for entrainment of fish during pumpback operation.

Survey locations and sampling schedule

Hydroacoustic surveys were performed at the 10 designated stations shown in Figure 1. These are referred to as Russell Dam (Station 1), Russell Tailwater (Stations 2 and 3 combined as one), main lake stations (Stations 7, 8, 9, and 10), and tributary stations (Stations 5, 6, and 11). The Russell Dam survey area encompassed the waters immediately below the dam from the lower dam face to 450 m downstream. Russell Tailwater extended from about 700 m to 6 km below Russell Dam. Each of the main lake and tributary stations encompassed a reach approximately 1.5 km long at the specifically chosen locations shown in Figure 1.

Acoustic data were collected each month from February 1986 through January 1987. Frequency of sampling was most intensive at Russell Dam and Russell Tailwater sampling stations. These areas were surveyed 14 times during the year including one sample every month and two samples each in April and May. The tributary and main lake stations were scheduled for quarterly sampling and during this reporting period were sampled in July, September, and December.

All surveys except Russell Dam were performed one time each during a sampling period. Scheduled sampling at these eight survey locations took place during the daylight hours. Additional nighttime sampling in the

Russell Tailwater was conducted a total of three times in June, July, and August.

Russell Dam was surveyed four times per sampling period at times of day corresponding to pregeneration, postgeneration (twice, usually on consecutive evenings), and nongenerating nighttime phases of the generating schedule. Russell Dam was the only station regularly sampled during nighttime hours.

Field methods

Data were collected using a dual-beam hydroacoustic system from Biosonics, Inc. The system was assembled around a Biosonics Model 101 Echo Sounder transmitting to and receiving from a Biosonics 420-kHz 6/15-deg dual-beam transducer. Other components were a Biosonics Model 171 Tape Recorder Interface, Sony Digitizer, Sony Cassette Recorder, Hitachi Oscilloscope, and an EPC Model 1600 Chart Recorder controlled by a Biosonics Chart Recorder Interface. The electronics were housed in the cabin of a 21-ft survey boat. The transducer was mounted inside a submersible stabilizing fin, and the entire unit was suspended about 0.5 m below the surface of the water from a boom located near the bow of the boat. The stabilizing fin allowed the transducer to remain downward-looking at all times during surveying.

Sampling was performed by towing the transducer through the water at a constant engine rpm with the echosounder emitting pulses at the rate of 5 or 10 pings/second. With each transmission pulse, a 6-deg, conical volume of water was ensonified as the pressure wave traveled through the water. The

rapid pulse rate produced a wedge of continuously sampled water as the boat traversed the survey route. Echo returns from all sources between surface and bottom were recorded on chart paper for visual display and to videotape for later analysis.

Acoustic surveys were designed as a system of fixed-location transects oriented from shore to shore across the channel. Transect locations at Russell Dam and Russell Tailwater were permanently marked at both sides of the channel by natural landmarks, reflectors, or fluorescent paint. Transects at each main lake and tributary station were approximately 500 m apart and typically located near reservoir navigation buoys. A total of 12 transects were run at Russell Dam, 11 in the Russell Tailwater, and 4 at each of the main lake and tributary stations. Beginning with the December survey, the effort at each of the tributary stations was increased from 4 to 11 transects. This midyear adjustment of sample size increased the precision of abundance estimates from the tributaries to a level comparable to Russell Dam and Russell Tailwater. Each transect typically required 2 to 15 min to sample depending on width of the channel at the transect location.

Data processing and analysis

Hydroacoustic survey data were processed to provide four types of fishery information: two measures of fish abundance, spatial distribution of fish in the water, and acoustic size of fish. The two measures of fish abundance were relative biomass density calculated in acoustic units that were approximately proportional to fish biomass and numerical density presented as fish per hectare of surface area of water.

There were 135 hr of acoustic data recorded during the first year of sampling. Analysis of this data was divided into two phases. First, the data tapes were processed to recover information recorded during survey sampling. This phase of analysis was aided by electronic processors designed to read taped data, identify fish echoes, and output statistics describing acoustical features of observed targets. Processing was performed by Biosonics, Inc., Seattle, Wash., and the resulting data were then sent to WES for synthesis and summarization. Conclusions were based on visual inspection of summary results. No attempt was made to substantiate conclusions using formal inference procedures.

Data for estimating relative fish biomass were extracted from videotapes using the Biosonics Model 121 Echo Integrator. This processor read data from tape, accumulated echo intensity readings of fish or fish groups detected during sampling, and outputted resulting summary values. Experience has shown that integrator processing yields data that are approximately proportional to fish biomass. For this reason, integrator measurements are referred to as relative biomass in this report.

Mean estimates of relative fish biomass were calculated in acoustical units as echo voltage squared per square metre of water surface area. Mean values of relative density were calculated for each survey station as the arithmetic mean of measurements of each transect in the survey.

Spatial distribution of fishes was evaluated only at Russell Dam. Transects in the Russell Dam survey were processed with the echo integrator into 10 segments of approximately equal length and 1-m-depth intervals

yielding a maximum of 120 cells of data values (Figure 2). The integrator reported relative biomass data for each cell, which were then standardized to a per volume basis as echo voltage squared per cubic metre of water. Thus direct comparisons could be made among cells to assess vertical and horizontal distribution of fish biomass.

Acoustic size measurements of individual fish were made on a per echo return basis with the Biosonics Model 181 Dual-Beam Processor. This processor separated single fish echoes from multiple fish echoes, and for each single fish target, calculated target strength adjusted for fish position in the transducer beam. Target strengths calculated for all single fish targets were then summarized for comparisons among stations and months. Target strength is an inherent property of a fish that is generally related to overall fish size, but target strength can differ for different species of fish or even the same individual fish with different orientations to the acoustic beam axis. Because species and orientation information was not, and usually is not, available from in situ measurements on fishes obtained during survey sampling, it was not possible to accurately relate measurements of acoustic size to the actual size of individual fishes. Target strength was assessed in the customary reporting units of decibels (dB). For convenient presentation in familiar units, target strengths in dB were also presented in inches using a regression equation developed by Love (1971). This relationship is shown graphically in Figure 3. It was developed from laboratory measurements of target strength made on several species of fishes, all of which were centered in the acoustic beam and positioned horizontally in the water at the time of measurement. Consequently, it is only an

approximate indication of relative fish size for in situ measurements and does not necessarily indicate actual fish size.

Fish density was estimated conceptually as total fish biomass divided by the mean biomass per fish and acoustically as the total echo intensity of all fishes divided by the mean echo intensity per fish. Data for these calculations were total echo intensity obtained from integrator processing and mean intensity per fish obtained from the dual-beam analysis of single fish targets. Estimates of fish density, like relative biomass, were computed for each sampling transect and summarized by survey.

Conditions encountered during tape processing necessitated occasional processing compromises to preserve the integrity of the data. One of these involved submerged trees that were present on several transects at Russell Tailwater, main lake, and tributary stations. To avoid integrating trees as fish targets, areas containing trees were excluded from processing by a manual windowing technique controlled by the processing technician. Thus, any fishes present in submerged timber were not usually included in the data. Exclusion by manual windowing was also used to eliminate layers of suspected insect larvae, thought to be bottom-dwelling Chaoborus spp., that sometimes migrated up into the water column in large numbers. The larvae were readily identified by their echogram traces. Debris in the water affected all seven stations in the December lakewide survey. The scheduled time of this survey immediately followed heavy rains that substantially raised water levels in the tributaries and main body of CHL. Debris that washed into the water was detectable during sampling. At all stations except Station 6; echoes from debris were substantially eliminated by a slight increase in the processor

noise threshold. Increased noise thresholding was not an effective eliminator of debris noise at Station 6; consequently, December data from Station 6 were omitted from presentation.

Main Lake Surveys and Comparisons with Russell Tailwater

Qualitative observations

Echograms recorded during sampling showed fish detections at all stations. Fishes were usually detected as individually resolvable single fish targets or as dense schools of fishes. Fishes occurring in dense schools were often packed too closely together to be individually detectable, and the resulting school appeared on the echogram as a continuous mass of fishes. Schools, where present, were often but not always detected in the upper portion of the water. Schools of fishes were detected at every sampling station. In some instances, they may have accounted for a sizable percentage of observed fish biomass.

Relative biomass

Acoustic estimates of relative fish biomass were expressed as echo voltage squared per square metre of surface area. Mean values of relative biomass varied widely from 0.001 to 0.068 among the seven whole lake sampling stations (Figure 4). Inspection of values for individual stations showed that fish biomass was consistently highest at one or more of the tributary sampling stations. For July and September, the 2 months when fish biomass

was highest, the three tributary stations ranked 1-2-3 and 1-2-5 among the seven stations. During both July and December, fish biomass was highest at tributary Station 11 in the Little River, Ga. In July, fish biomass was highest at tributary Station 6 in Little River, S. C.

Inspection of mean biomass values at main lake stations numbered 9, 8, and 7 showed progressively higher levels of fish biomass in the main body of CHL Reservoir closer to the project area (Figure 4). This trend, evident in both July and September, followed a similar trend reported for chlorophyll concentrations elsewhere in the workshop, suggesting a relationship between primary productivity and fish standing crop.

Estimates of relative biomass for individual stations in the whole lake survey were pooled into groups corresponding to tributary stations and main lake stations. For tributary stations, mean biomass was 0.046, 0.025, and 0.009 for the months of July, September, and December respectively. During the same months, mean relative biomass at main lake stations was 0.018, 0.011, and 0.007 (Figure 5). Two trends in these summary statistics were apparent. First, there was a consistent decline in fish biomass from July to September to December. This trend was observed at both main lake and tributary stations. The threefold to fourfold reduction of biomass from July to December probably indicated a change in fish distribution or detectability rather than a marked reduction of fish standing crop. The second observable trend was that fish biomass was consistently higher in the tributaries than in the main lake. The amount by which fish biomass per surface area in the tributaries exceeded levels in the main lake was approximately 260 percent in July, 220 percent in September, and 30 percent in December.

In comparison, relative biomass of fish in the Russell Tailwater ranged from 0.002 to 0.051 from February 1986 through January 1987. There were large monthly differences from March through September with no discernible trends in these months (Figure 6). Periods of highest biomass all occurred from March through September with peaks in March (0.035), late May (0.021), and September (0.051). Over the entire year, biomass was consistently low from October through January at levels that were similar to those observed at tributary and main lake stations in December. Mean biomass measured in the Russell Tailwater varied from about 1/2 to 2 times the mean level of the tributary stations for the 3 months that both were sampled.

Fish density

Fish density was computed as numbers of fishes per hectare of water surface area. This included all sizes of fishes approximately 1 in. long and larger. Mean fish density at the individual lakewide stations varied from 4 to 2,623 fishes/ha and showed no obvious trends (Figure 7). Pooled estimates for the tributary stations yielded mean fish densities of 1,059, 1,452, and 859 fishes/ha for the months of July, September, and December, respectively. Similar pooling for main lake stations yielded densities of 416, 816, and 859 fishes/ha for the same months (Figure 8). Mean fish densities did not show the steady decline from July to September to December as observed with relative biomass due to differences in the size distributions of fishes during these different months. However, both measures showed comparatively greater fish abundance in the tributaries during July and September, the 2 months for which mean density and biomass were generally highest.

Density of fishes in the Russell Tailwater varied widely from 28 to 1,705 fishes/ha between February 1986 and January 1987 (Figure 9). This was similar to the range of values measured at individual stations in the tributaries and main body of CHL. Seasonal trends in density were not apparent. The pattern of monthly variation in fish density was similar to that observed for relative biomass with peak densities observed in March (304), early May (374), and September (1,705).

Acoustic size of fish

Acoustic size of fishes was evaluated using echoes identified by the Dual-Beam Processor as single fish targets. Measurements from single fish echoes were summarized as frequency histograms showing the relative number of fish echoes occurring in successive 2-dB-size increments. Resulting frequency histograms were inspected for differences among sampling stations and among months of the year.

Acoustic size distributions from the whole lake surveys are shown for tributary stations in Figure 10 and main lake stations in Figure 11. Sample sizes from individual monthly surveys were low ranging from <50 to 177 fish echoes. Surveys with <50 echoes are not shown. Frequency histograms were unstable and varied widely among stations and months of sampling. This was due, in part, to small sample size resulting from the low number of single targets detected during sampling.

To increase sample size, individual stations were pooled into two groups corresponding to tributary and main lake stations, and these were compared

with acoustic size distributions of fish sampled in the Russell Tailwater and Russell Dam sampling stations (Figure 12). The pooled frequency histograms had sample sizes ranging from 73 to 2,046 echoes. The acoustic size of these fish ranged from -65 to -27 dB (0.3 to 36 in.). There were generally few fish observed between -65 and -60 dB (0.3 to 0.7 in.). All areas sampled showed rather typical size class variation with large numbers of small fish and decreasing numbers of progressively larger fish.

A detailed comparison of acoustic size distributions was made among the tributary, main lake, Russell Dam, and Russell Tailwater sampling stations for the months of July and September (Table 1). These were months for which sufficient data were available from both lakewide and project area surveys. Small fishes were numerically dominant in all areas surveyed. This was indicated by the abundance of fish echoes smaller than -41 dB (<7 in.), which ranged from 78 to 96 percent of all single fish echoes. Included in this size class were fishes from the dense schools that were sampled. Because many fishes present in schools were crowded too closely together to be resolved as single targets, the numerical frequency of small fishes was underestimated from these data.

Small fishes, those <41 dB, showed two noteworthy features. First, their relative abundance was 7 to 12 percent greater in September than July (Table 1). This was a consistent trend in all areas sampled. Several explanations are plausible, but the trend may, in part, reflect aging of the 1986 recruitment class. During July, recruits would be small in size and would tend to occur nearshore or other cover where acoustics was not completely effective. By September, larger size and changes in behavior would make the

recruits more detectable with acoustics. The second feature of small (<41 dB) fishes was their lower relative occurrence in the CHL tributaries compared with the other areas sampled (Table 1). In the main lake, in the Russell Tailwater, and at Russell Dam, small (<41 dB) fishes were 86 to 87 percent of all single targets detected in July and 94 to 96 percent of all such targets in September. In contrast, the percentage of small fishes in the tributaries averaged 8 to 9 percent lower in July (78 percent) and 4 to 6 percent lower in September (90 percent). Overall, the relative frequency of small fish detected in the project area was more similar to the main lake region of Clarks Hill Reservoir than to other tributaries.

The upper tails of the frequency histograms indicated relative abundance of larger fishes on a per echo basis of measurement. About 0 to 3 percent of all single fish echoes were >-31 dB (>23 in.) in acoustic size (Table 1). Though low in numerical frequency, these fishes would represent a more substantial portion of the standing crop if they could be represented as a percentage of total weight rather than number.

Near Project Comparisons

This section summarizes the results of hydroacoustic surveys in the area immediately below Russell Dam and in the Russell Tailwater downstream to the confluence of the Savannah River with the Broad River. The primary objective for hydroacoustic surveys in the tailwater area (away from the immediate vicinity of the dam) was to assess the monthly changes in fish abundance relative to Russell Dam and to other areas of CHL. A second objective was to assess the monthly changes in target size distribution. Survey objectives

for the area close to Russell Dam can be described broadly as follows: (a) to provide a comparison of fish biomass and densities near the dam with biomass and densities in the downstream tailwater, (b) to describe temporal patterns of fish distribution, and (c) to describe spatial patterns of fish distribution. Surveys were scheduled to ascertain temporal patterns of distribution both on a seasonal basis and on a short-term basis with respect to day-night cycles and hydropower releases. Seasonal patterns of distribution were determined by conducting monthly surveys close to the dam and in the tailwater, with special emphasis on the spawning periods of April and May, when two surveys per month were conducted. Shorter term patterns of temporal distribution were made with a series of diel surveys. Spatial patterns of fish distribution were assessed in the following dimensions: (a) longitudinal distance from the dam, (b) depth below the water surface and distance above the bottom, and (c) laterally along each transect.

Russell Tailwater

Tailwater transects (13 to 23) extended from about 700 m below the dam to about 6 km downstream (Figure 13). Each transect was roughly perpendicular to the main axis of the lake and was surveyed west to east, from the Georgia side of the channel to the South Carolina side. All routine tailwater surveys were conducted during daylight hours and without regard to hydropower releases.

As discussed earlier, overall results of surveys in the tailwater showed no consistent pattern, although biomass was consistently low in the winter and fall months (Figure 14). Surveys were conducted during daylight hours

except during July, August, and September when night surveys were conducted in addition to the daytime surveys. These night surveys were performed to determine how much the time of day affected sampling results. Biomass results were higher for 2 of the 3 months at night when compared with the daytime surveys for the same months. Overall results for the tailwater were similar to lakewide results for July, August, and September (see Figure 6).

There was roughly twice the density of fishes in the tailwater at night for the 3 months sampled when compared with the results seen during the day (Figure 15). While biomass for September was slightly lower at night, densities were higher, suggesting that greater numbers of smaller fishes were present in September. This result was also indicated by the average target size of -48.3 dB in September versus -40.2 dB in August (corresponding to 4 in. and 10 in., respectively, based on Love's formula).

Russell Dam

It was not possible to conduct complete surveys during hydropower releases due to interference from turbulence and entrained air in the water column during flow. Sampling during the nongeneration period was divided into several periods. The period immediately after flow ceased was called the postgeneration sample, coded as RDA (Russell Dam after generation). A survey after a period of time with no releases was called the pregeneration sample, coded as RDB (Russell Dam before generation); this survey was always conducted during daylight hours. A nighttime sample after a period of no releases was coded as RDN (Russell Dam night). This survey commenced 1 hr after sunset and was typically performed on a weekend 24 to 48 hr after the

previous release. More detailed information on changes in fish distribution over a 24-hr period was obtained from a series of diel surveys, discussed below.

The RDB and RDN surveys were used to compare differences between day and night, since the RDB surveys were conducted during the day and the RDN surveys only at night. Initially, each of the RDB and RDA surveys was repeated for each monthly or twice monthly survey to establish the amount of variability within a survey period. Since densities during the day tended to be very low, the RDB replicate was dropped after June 1986; the RDA survey was replicated continuously through 1986 and the first half of 1987. Because RDA surveys were conducted during the day or at night, depending on the generation schedule, it was not possible to separate the effects of the release schedule from day/night effects with this design. This problem was addressed by the diel surveys.

Figure 16 shows the generating schedule for February 1986 through March 1987 along with the sampling times for each survey. The vertical axis shows the time of day from midnight to midnight. Each hour of generation on a particular day is represented by a solid vertical bar. There were basically two patterns of generation: a morning and an afternoon release each weekday from mid-October through April, and one afternoon/evening period of release each weekday from May through October. Solid lines indicate the local time of sunrise and sunset, with abrupt shifts in the line indicating change to daylight and standard times in April and October, respectively. Various symbols indicate the different survey types and the time they occurred. RDB surveys were always conducted during the day and usually at least 4 hr after

the end of the preceding generating period. RDN surveys were scheduled 1 hr after sunset on a weekend without generation. The RDA surveys were started as soon as possible after a release period, usually within 15 to 20 min of shutdown. Due to variation in the generating schedule throughout the year, the RDA surveys occurred at various times during the day, most often after dark during the summer months but during the day at other times of year. Each survey typically required 1.5 hr to complete all 12 transects near the dam.

Lake elevations were much lower than normal because 1986 was a drought year for this area (Figure 17). Much of 1986 from April through December had the lowest water surface elevation of the past 25 years. Lower lake levels may have had an effect on fish populations near the dam, especially during the fall months when water depths were very shallow in the tailwater area approaching the dam. The tailwater area within 1 km of the dam had extensive shoal areas in October 1986 when the lake was 12 to 13 ft below full pool and 8 to 9 ft below normal for that time of year.

Figure 18 shows the transect layout in the tailrace area near RBR Dam. The first five transects were closer together to provide greater detail on fish distribution close to the draft tube openings. The spacing was 25 m between transects for the first five transects and 50 m between transects for the remaining seven. When survey data were processed, each transect was divided into 10 approximately equal segments and into 1-m depth intervals so that information on fish distribution along each transect could be obtained. All 12 transects were run for each survey except when water levels were too

low; for the latter half of 1986, Transects 10, 11, and 12 were too shallow to survey.

Pooled results for the dam and tailwater areas for the various survey periods in terms of relative biomass are illustrated in Figure 19. In those instances when surveys were replicated, data were combined to provide the average value shown. The downstream tailwater data (as shown in Figure 2) are indicated by the RTD and RTN surveys, but on a compressed scale as compared with the earlier figure. Tailwater survey results, both day and night, were similar to biomass measured at the dam during the day as represented by the RDB survey. Much greater biomass was revealed near the dam at night (RDN surveys) for May through September, and the difference between day and night was much greater for the dam area than in the downstream tailwater. The postgeneration RDA surveys were also higher in biomass than the pregeneration surveys done during the day. The April, May, June, and September RDA surveys were all done at times comparable with the night surveys for those months, while those in July and August were done earlier than the night surveys, usually just before sunset. Thus, some of the variability in the postgeneration surveys can be accounted for by sampling during daylight hours.

Figure 20 shows the same set of data in terms of fish density. There were higher numbers of fishes during May and August for both the RDN and RDA surveys, but somewhat lower numbers during June and July. Since biomass during those months remained high for the RDN surveys, this suggests that there were fewer numbers of larger sized fishes for those months. Numbers of

fishes in the tailwater (RTD) were also comparable with numbers at the dam during the day (RDB).

Figure 21 compares target strength distributions for the months of May, June, July, and August for the tailwater area (RTD) in comparison with the dam area for the pregeneration day sample (RDB) and the night sample (RDN). These results indicate a predominance of smaller targets near the dam at all times for these months and a greater proportion of smaller targets during the day as compared with night. This pattern remained fairly constant throughout the 4-month period. The downstream tailwater region showed a less consistent pattern, with a somewhat greater proportion of larger targets in May and August than in June or July.

Figure 22 compares target strength distributions for the three survey types at the dam from May to August. The distributional patterns remained fairly constant within survey type for these 4 months, with a greater proportion of smaller targets for the pregeneration (RDB) survey as compared with either the postgeneration (RDA) or night (RDN) surveys. Between 80 and 90 percent of the targets were -44 dB or less, corresponding to fishes 4.7 in. or less in length.

Diel surveys were designed to determine patterns of fish distribution on a finer time scale than the routine monthly or twice monthly surveys. A trial survey conducted in September 1986 is reported here. The diel survey design included only the first 7 transects since these were closest to the project and could be surveyed within 1 hr. The diel surveys started with a routine postgeneration (RDA) survey of all 12 transects followed by a survey

of the first 7 transects repeated hourly for 3 hr and then every 2 hr until the next scheduled generation release. This pattern was repeated starting with the night (RDN) survey for the same month, 2 nights after the start of the RDA survey and continuing through the next day.

Diel results for September 1986 showed considerably higher biomass levels for the night (RDN) surveys as compared with the postgeneration (RDA) surveys (Figure 23). There appears to have been a decline in biomass as the night progressed during the RDN surveys. Higher biomass levels were found after the nongeneration period as compared with the postgeneration period. Lower biomass was also observed during daylight hours for both survey types. However, these results may have been atypical because of low-water conditions at that time. Shallow water in the tailrace may have blocked potential fish migration to the dam area.

The pattern of distribution of fishes with distance from the dam is shown for the various survey types in Figure 24. The composite results are shown for the high biomass period of April through September for each of the three survey types. Lowest overall biomass was observed for the daytime pregeneration surveys (RDB), with higher levels seen during the postgeneration (RDA) surveys, and highest levels observed during the night (RDN) surveys after a period of nongeneration. Highest biomass was found at the transect closest to the dam with a rapid decrease moving downstream, except during the RDN survey that showed a slight increase at a distance of 150 to 200 m downstream. A similar pattern was observed for data presented in terms of fish density.

Replicate pairs of RDA surveys for 3 separate months indicated some of the variability within survey made 1 day apart (Figure 25). Each pair shows the transect-by-transect results for two postgeneration surveys; members of each pair were sampled at the same time of day. The replicates showed a fairly consistent and similar pattern, although there was more variability for the lower density periods, especially in March when the surveys were conducted during daylight hours. Intermediate densities were observed for the August samples, which were surveyed just before sunset, while highest densities were observed for the May samples surveyed after dark. The May samples also showed high densities very close to the dam.

Individual RDN surveys showed fairly consistent patterns during the high biomass periods. Except for March and April, there were high levels close to the dam, with an initial decrease moving away from the dam for the first 50 to 75 m, followed by a slight increase at 150 to 200 m, and a decrease beyond that point.

Depth distributional patterns should be considered with respect to the tailrace bathymetry (Figure 26). Data from each transect were processed to provide 10 equal segments laterally and 1-m-depth increments into the water column (Figure 2). Figure 27 illustrates an RDN survey for Transect 1 on 18 May 1986, which was started at 2140 hr; the water surface elevation on that date was 324 ft above mean sea level, and the distance to the dam was about 5 m. Fish biomass levels are indicated by shading intensity with the highest values indicated by the darkest shades and progressively lower biomass indicated by lighter shades. The scale is logarithmic, with the lowest level at 0.0001 v^2/m^3 or less indicated by the lighest shading

level. The highest biomass level (greater than 1 v^2/m^3) corresponds approximately to a fish density of 1 to 10 fishes/m^3 with an average fish length of 4 to 6 in. Note that the temperature profile indicates stratified conditions for this period. Figure 28 illustrates results for Transects 1 through 12 together for this survey. Most of the fishes were located above the thermocline; this pattern was frequently observed during the spring and summer period when a thermocline was present.

Figure 28 shows Transects 1-12 together in a side view for the same date; Figures 29-41 illustrate the general distributional pattern for selected surveys for the spring and summer of 1986 for various survey periods. The distributional pattern was more sporadic for the RDA surveys, and those surveyed near dusk in July showed lower densities than night surveys. RDB surveys also showed much lower densities since they were made during the day.

Summary

Main lake surveys compared with Russell Tailwater

Survey estimates of relative fish biomass, measured as echo voltage squared per square metre of water surface area, varied from 0.002 to 0.051 in the Russell Tailwater and 0.001 to 0.068 for individual stations in the whole lake survey. Monthly samples in Russell Tailwater indicated two distinct periods of the year with low levels of fish biomass from October through February and high levels occurring irregularly from March through September. Relative biomass in Russell Tailwater varied from about 1/2 to 2 times the levels measured at tributary stations in the 3 months that both were

measured. At the lakewide survey stations, relative biomass consistently decreased from July to September to December at both tributary and main lake stations. Mean levels of relative biomass were also consistently higher at tributary stations than at main lake stations during all 3 months sampled. Fish density varied from 28 to 1,705 fishes/ha in the Russell Tailwater and 4 to 2,623 fishes/ha at individual stations in the whole lake survey. Monthly changes in density in Russell Tailwater paralleled changes observed in biomass with low densities from October through January and high densities from March through September. Comparison of fish density among whole lake survey stations showed less clear trends than similar comparisons for relative biomass.

Acoustic size of single fish targets varied from -65 to -27 dB (0.3 to 36 in.). Small fish predominated in all areas sampled with 78 to 96 percent of fish echoes less than -41 dB (<7 in.).

Near project comparisons

Temporal trends of fish distribution below RBR Dam based on hydroacoustic surveys can be summarized as follows: (a) highest biomass was observed from May to August in 1986; (b) biomass was somewhat lower for the postgeneration surveys as compared with the night surveys, but due to the variable release schedule, it was difficult to separate the effects of the day-night cycle from the effects of release; and (c) day-night differences were much more pronounced near the dam than in the tailwater.

Spatial trends of fish distribution below RBR Dam based on hydroacoustic surveys can be summarized as follows: (a) highest biomass was found on Transect 1 closest to the dam for all survey types; (b) most biomass was within the top third of the water column; and (c) fish biomass at the dam consisted mostly of small targets, generally less than 6 in. in length.

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Table 1

Target Strength (TS) Summary Statistics

Month	Stations	Median TS	Percent <7 IN. (-41 dB)	Percent >23 IN. (-31 dB)
Jul	Tributaries	-50	78	2.3
	Main Lake	-56	87	3.2
	Russell Dam	-52	87	0.5
	Russell Tailwater	-50	86	0.1
Sep	Tributaries	-52	90	0.0
	Main Lake	-54	95	0.0
	Russell Dam	-54	96	0.0
	Russell Tailwater	-54	94	0.5

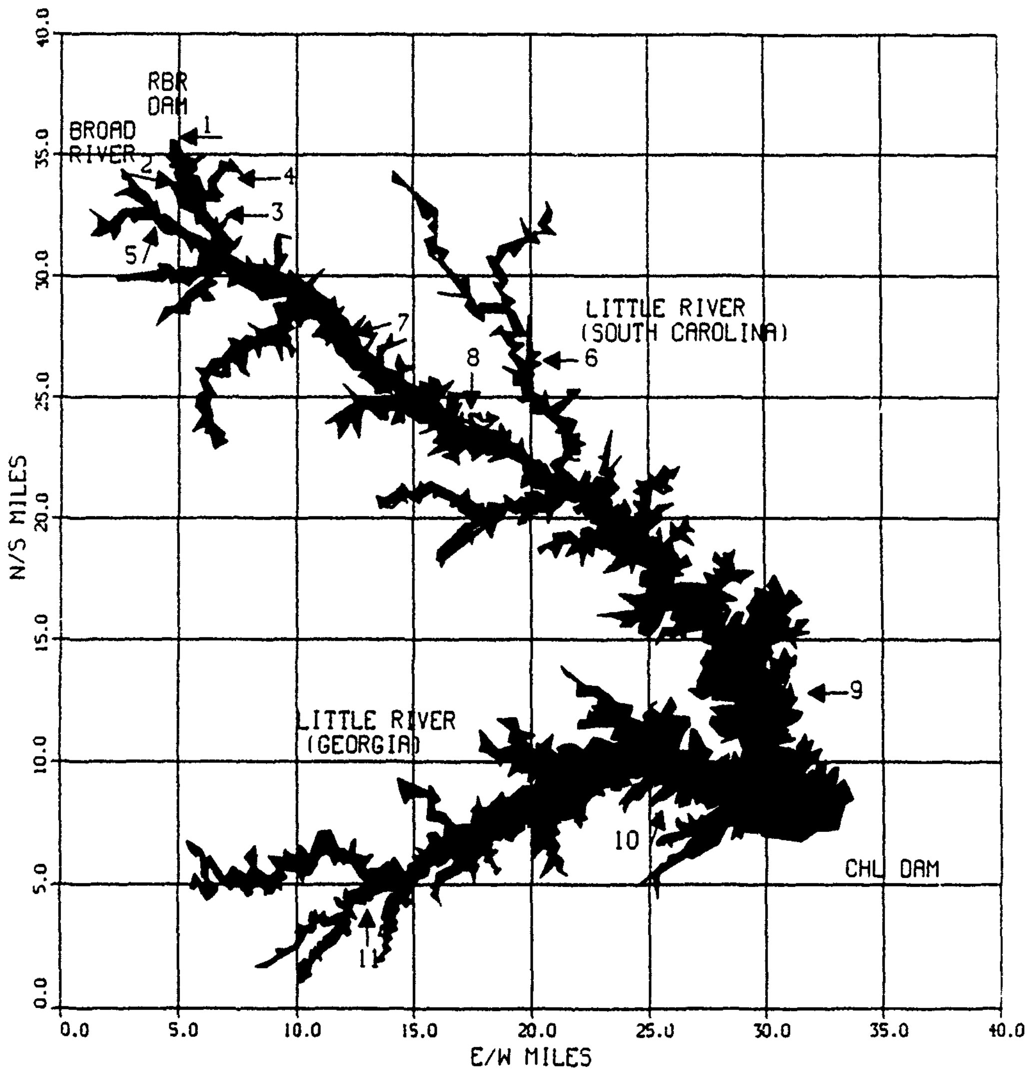


Figure 1. Location of hydroacoustic survey stations

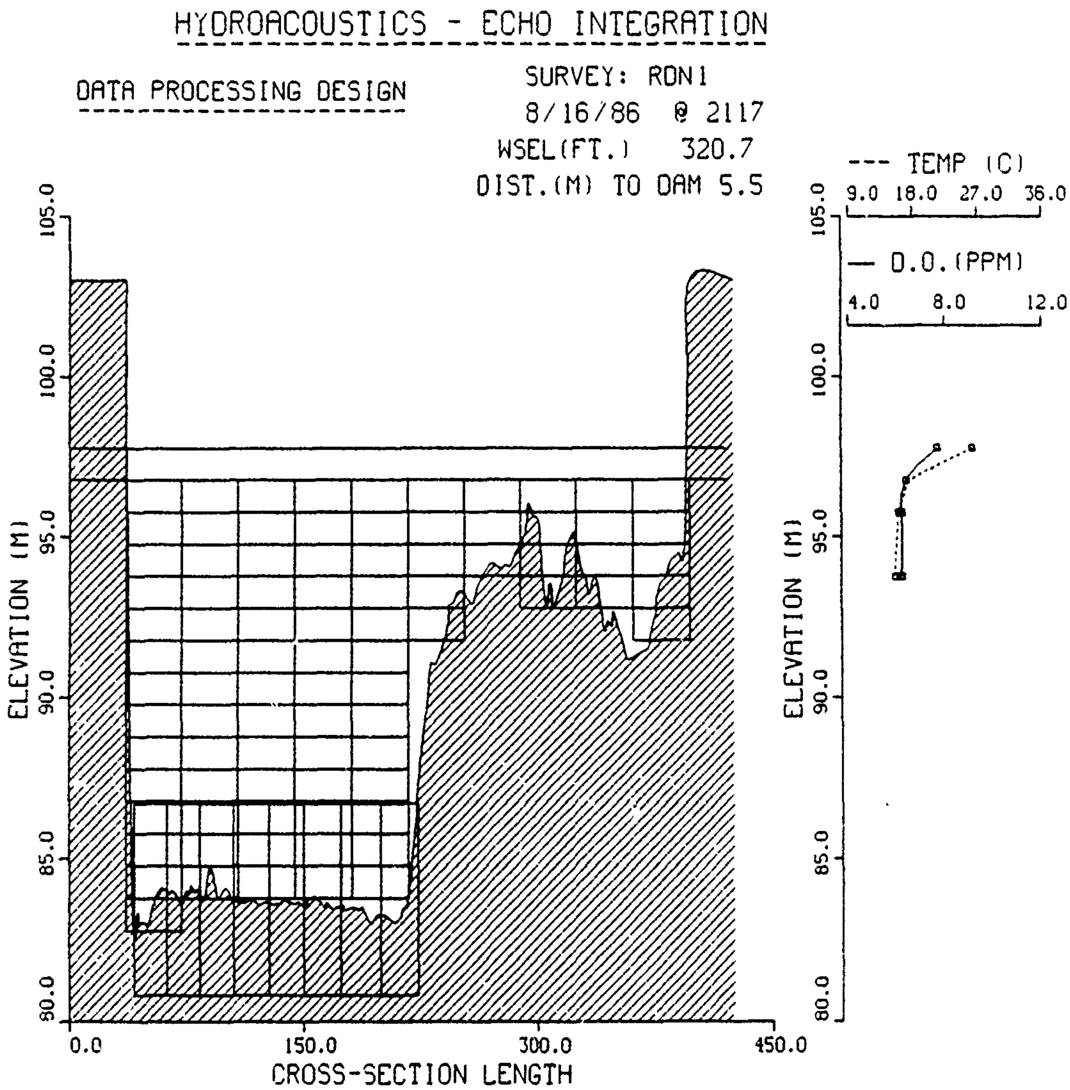
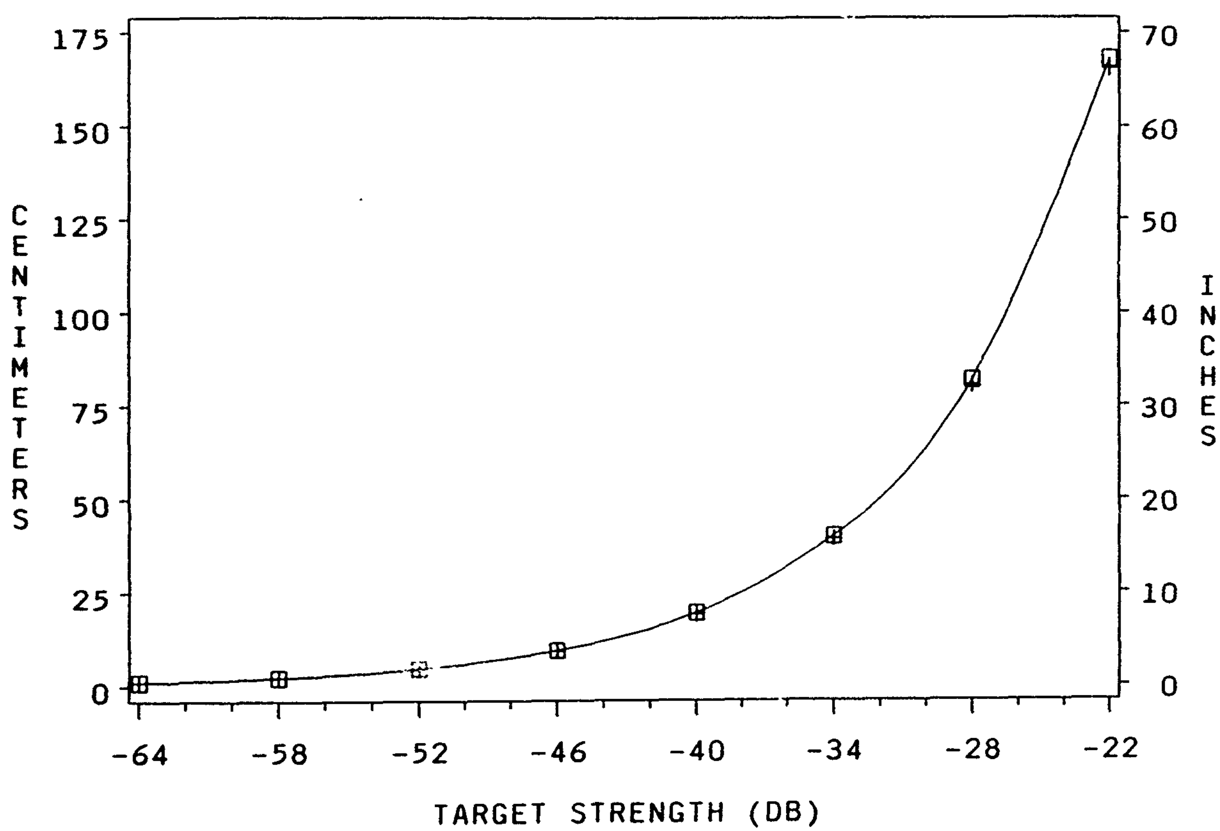


Figure 2. Schematic representation of data cells for spatial analysis of fish distributions



AVERAGE EMPERICAL RELATIONSHIP
DERIVED BY LOVE(1971)

Figure 3. Conversion of target strengths (dB) to fish size from the regression equation by Love (1971)

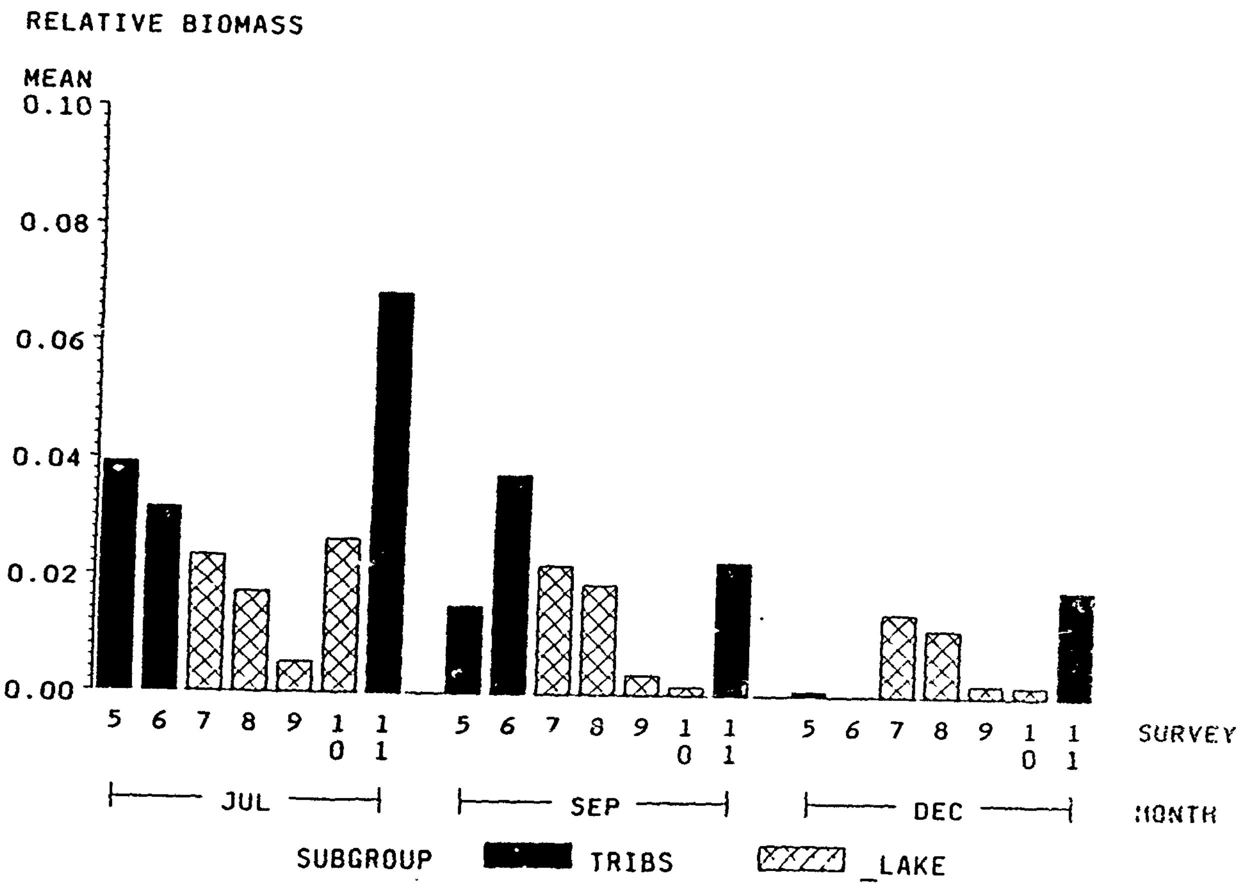


Figure 4. Relative fish biomass (v^2/m^2) at seven sampling stations in CHL Reservoir

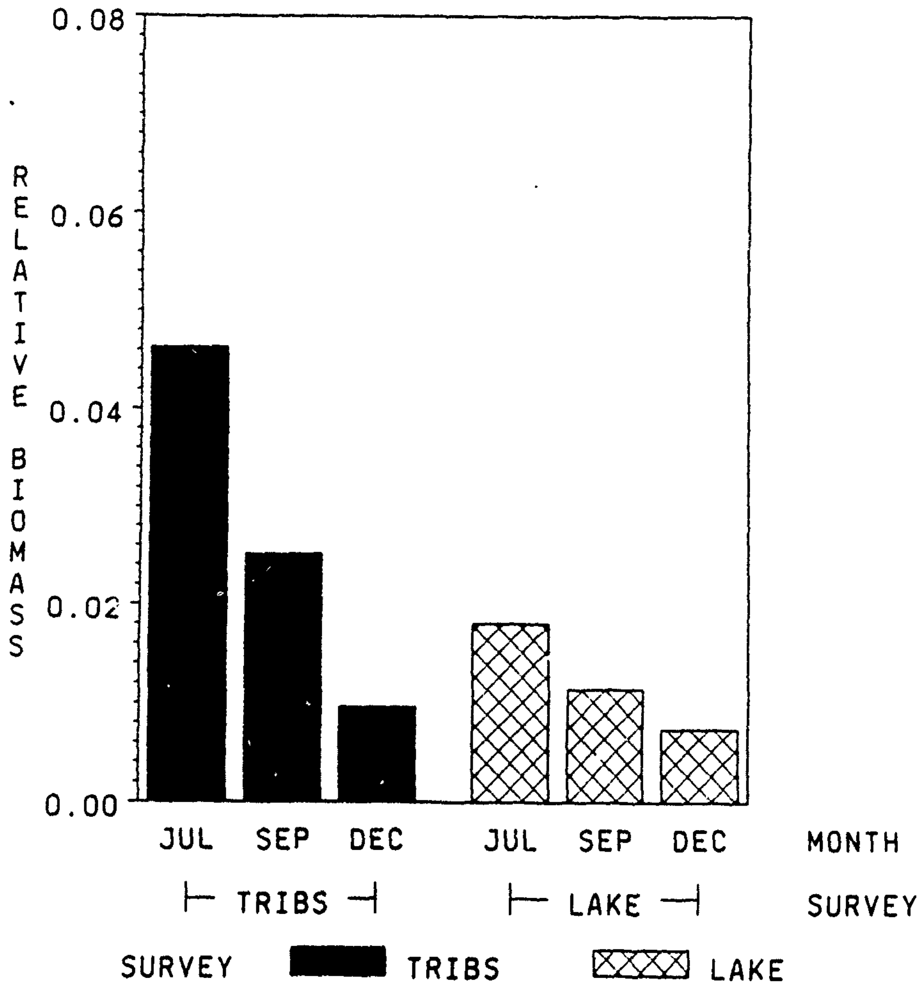


Figure 5. Relative fish biomasses at tributary and main lake sampling stations

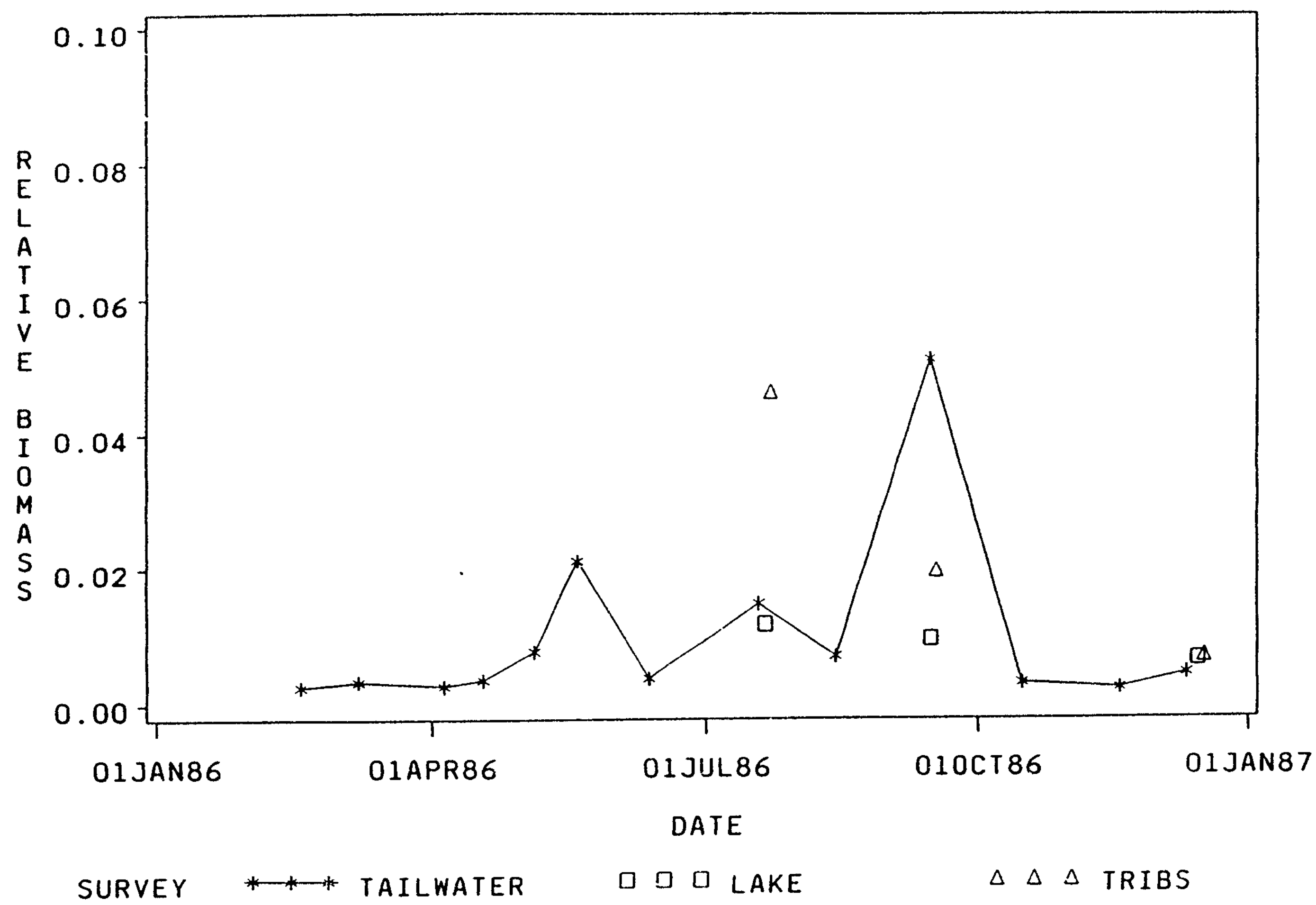


Figure 6. Relative fish biomass in the Russell Tailwater and comparisons to background levels in CHL tributary and main lake areas

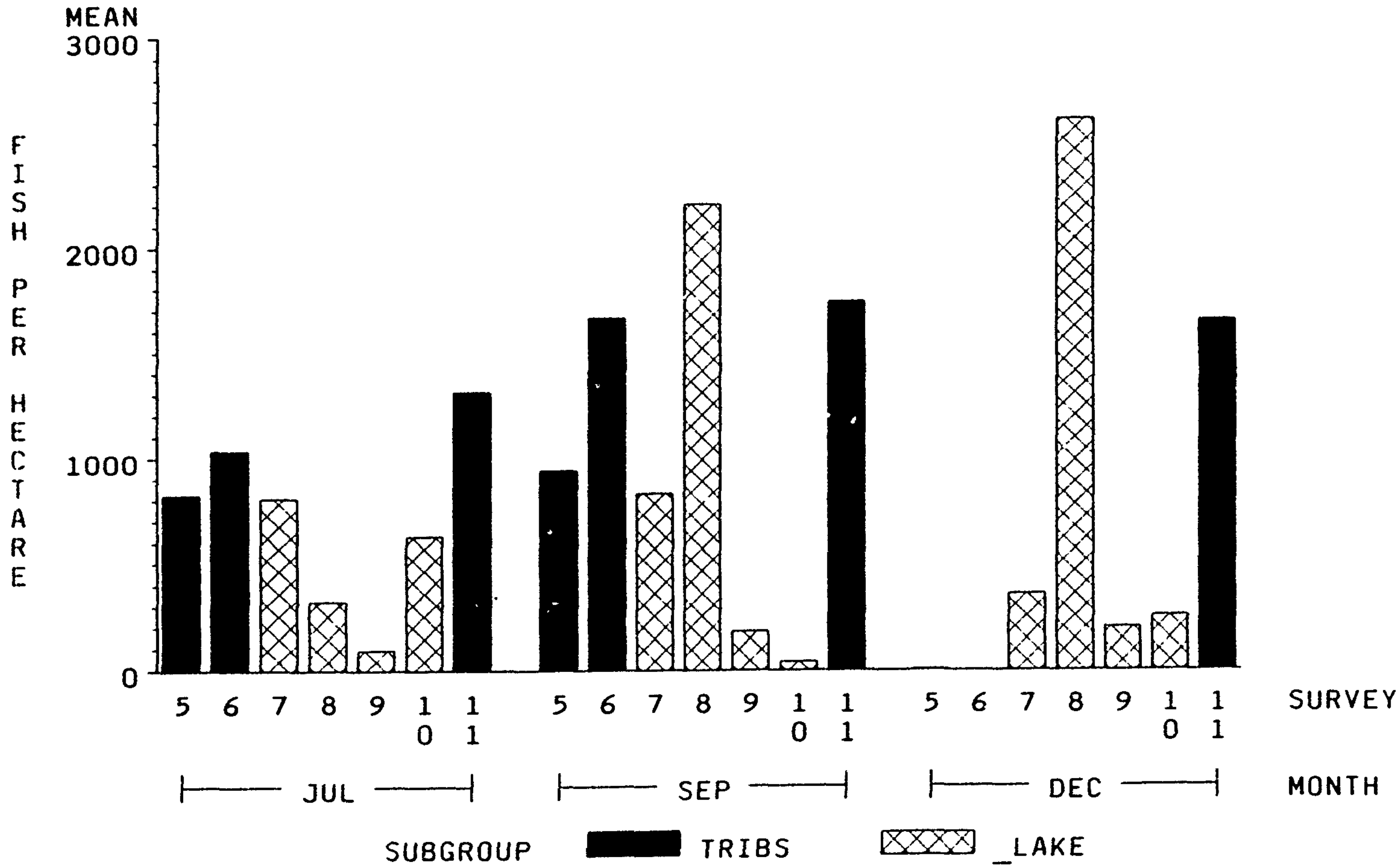


Figure 7. Numbers of fishes per hectare at seven sampling stations in CHL Reservoir

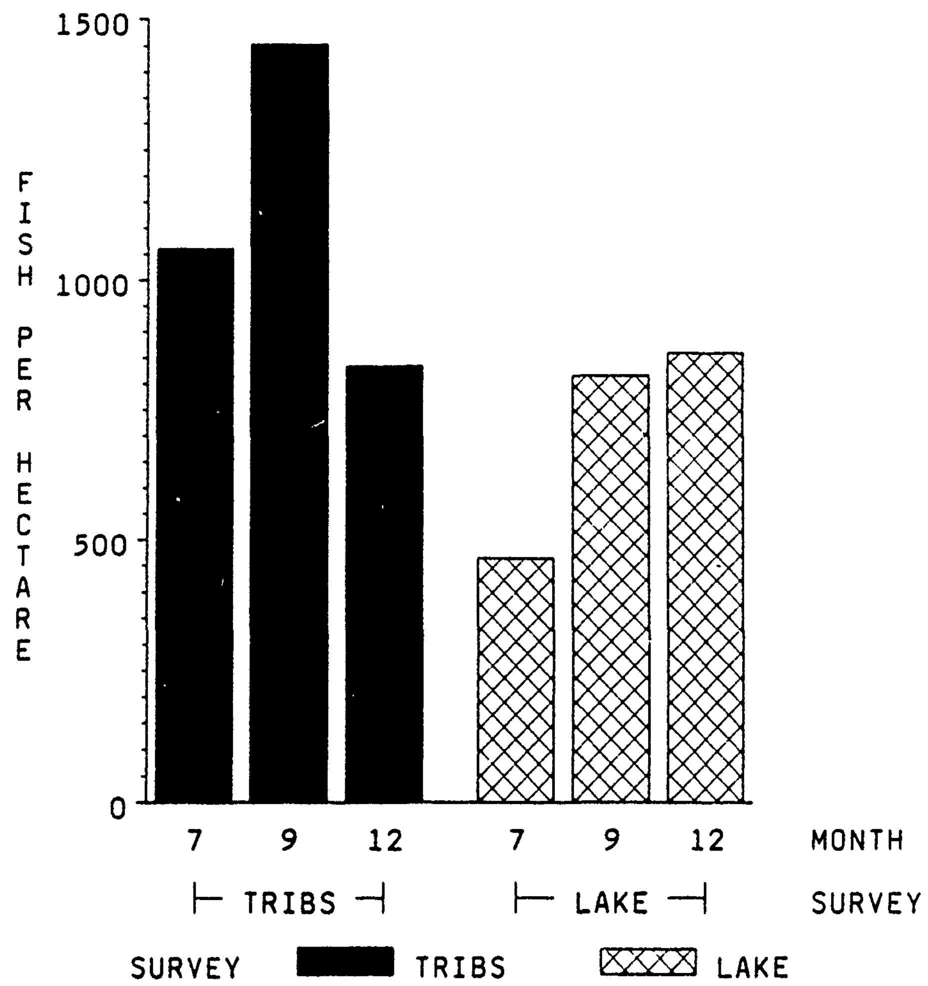


Figure 8. Numbers of fishes per hectare at tributary and main lake sampling stations in CHL Reservoir

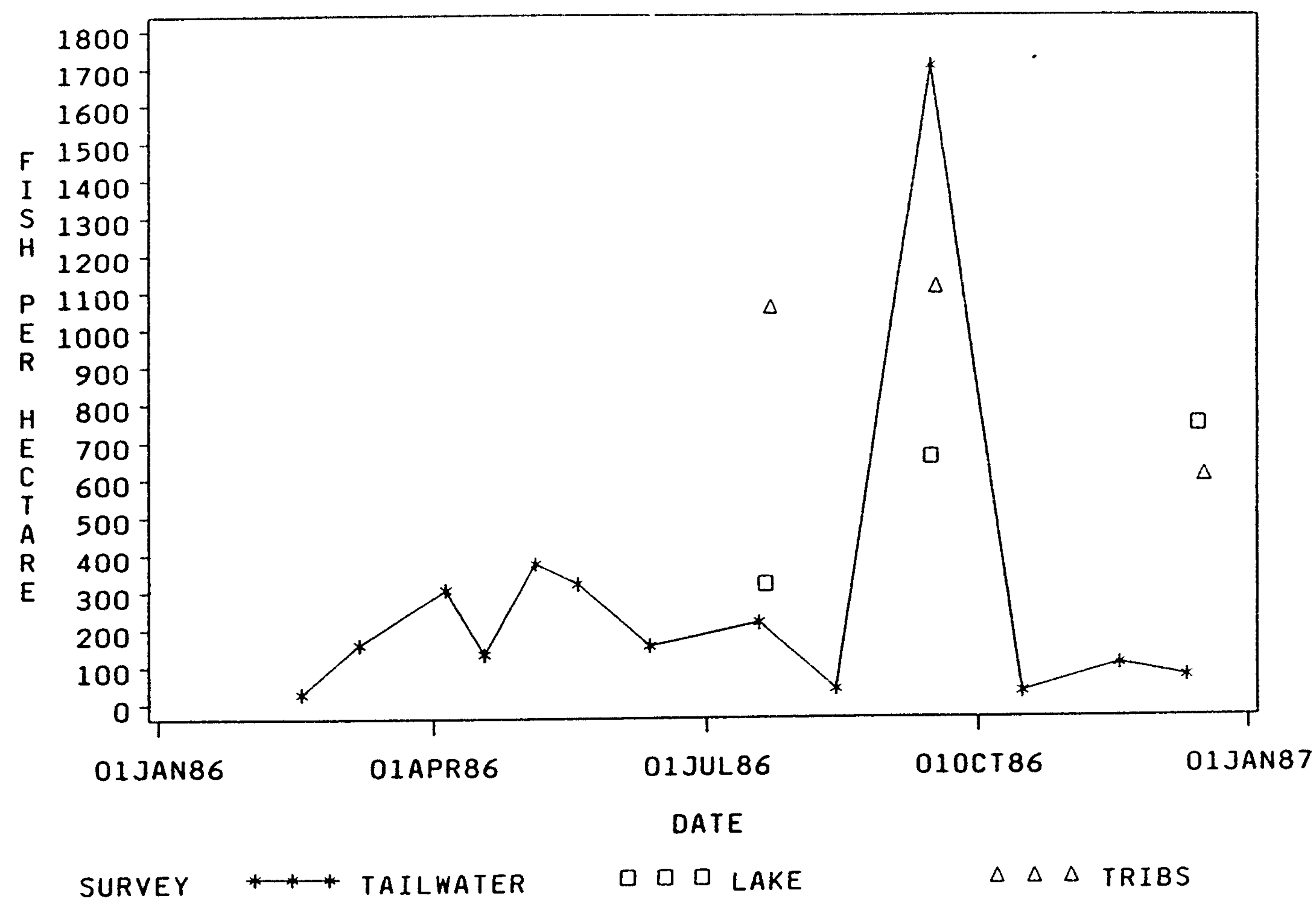


Figure 9. Numbers of fishes per hectare in the Russell Tailwater and comparisons with background levels in CHL tributary and main lake stations

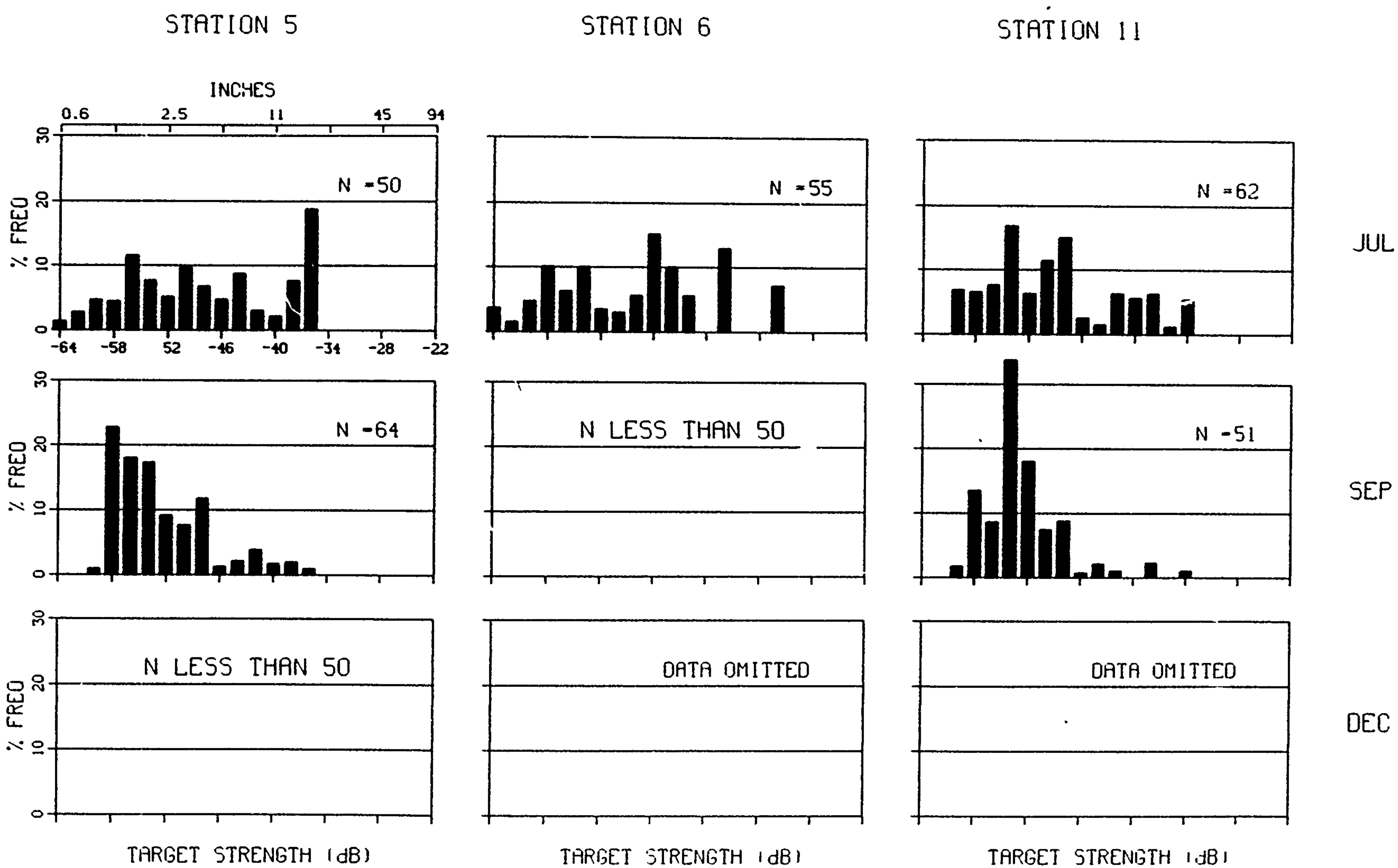


Figure 10. Histograms of acoustic size frequency at tributary stations

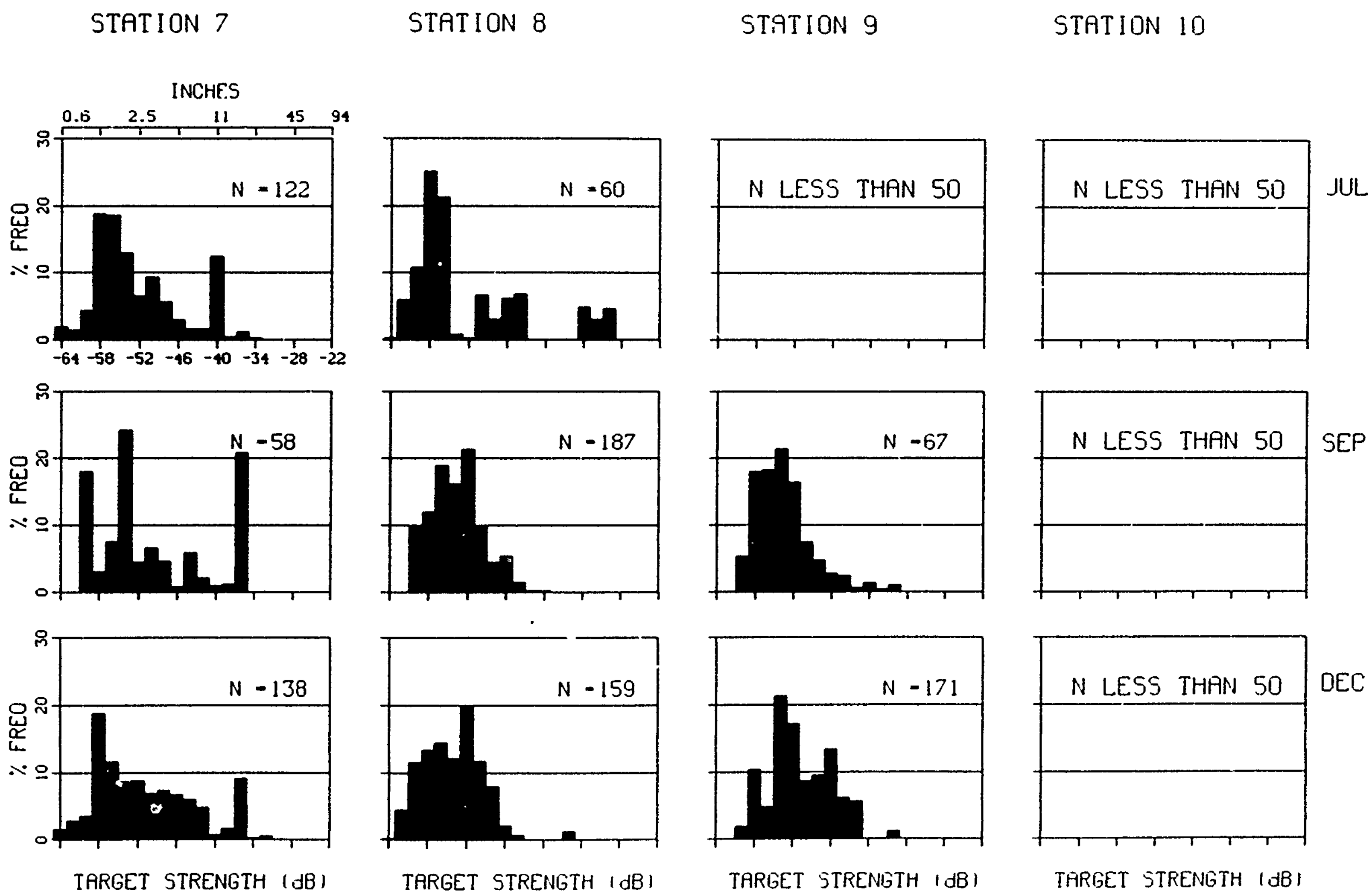


Figure 11. Histograms of acoustic size frequency at main lake stations

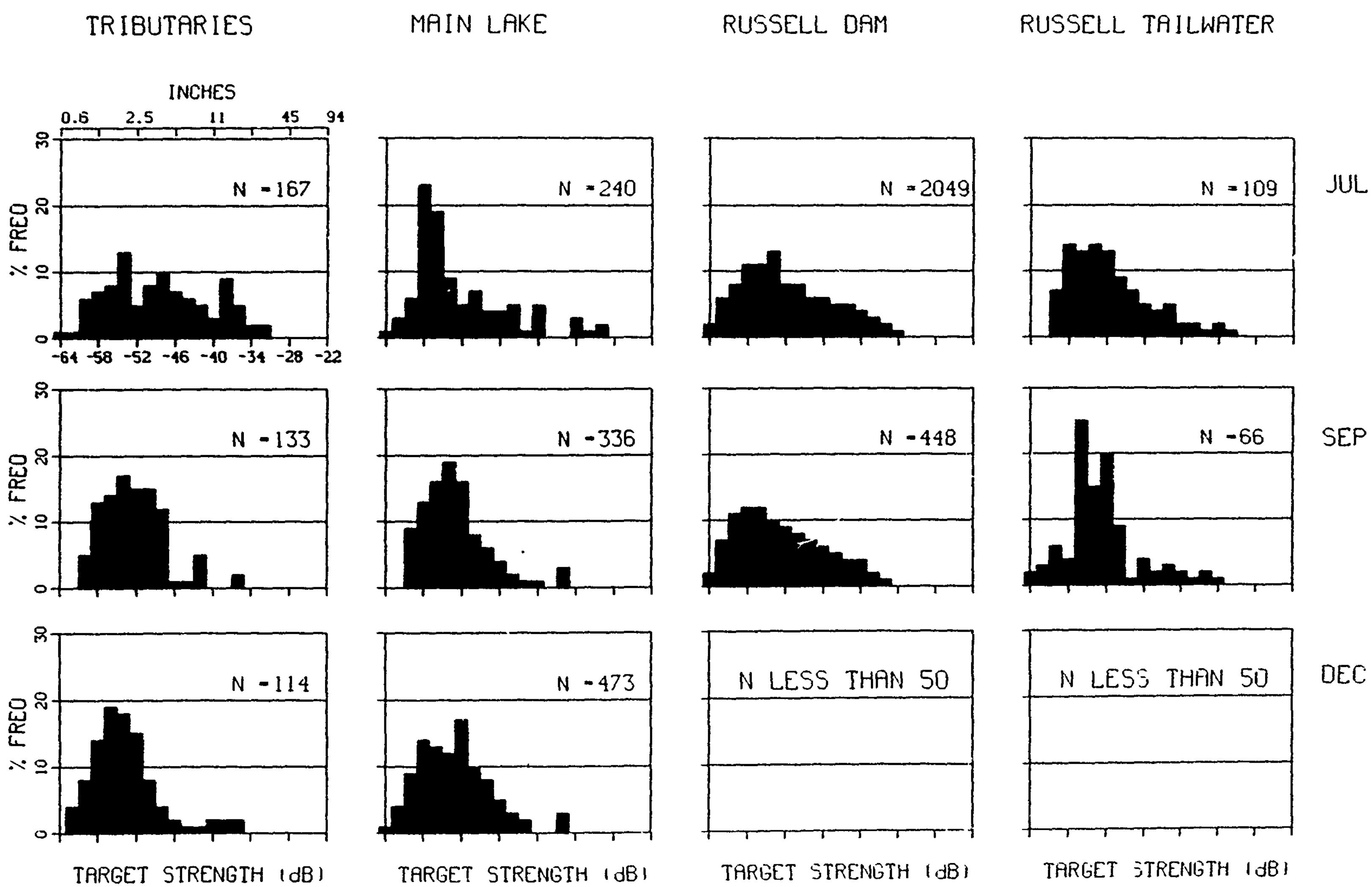


Figure 12. Histogram comparison of acoustic size among all areas sampled

RBR HYDROACOUSTIC SURVEYS

TAILWATER TRANSECTS

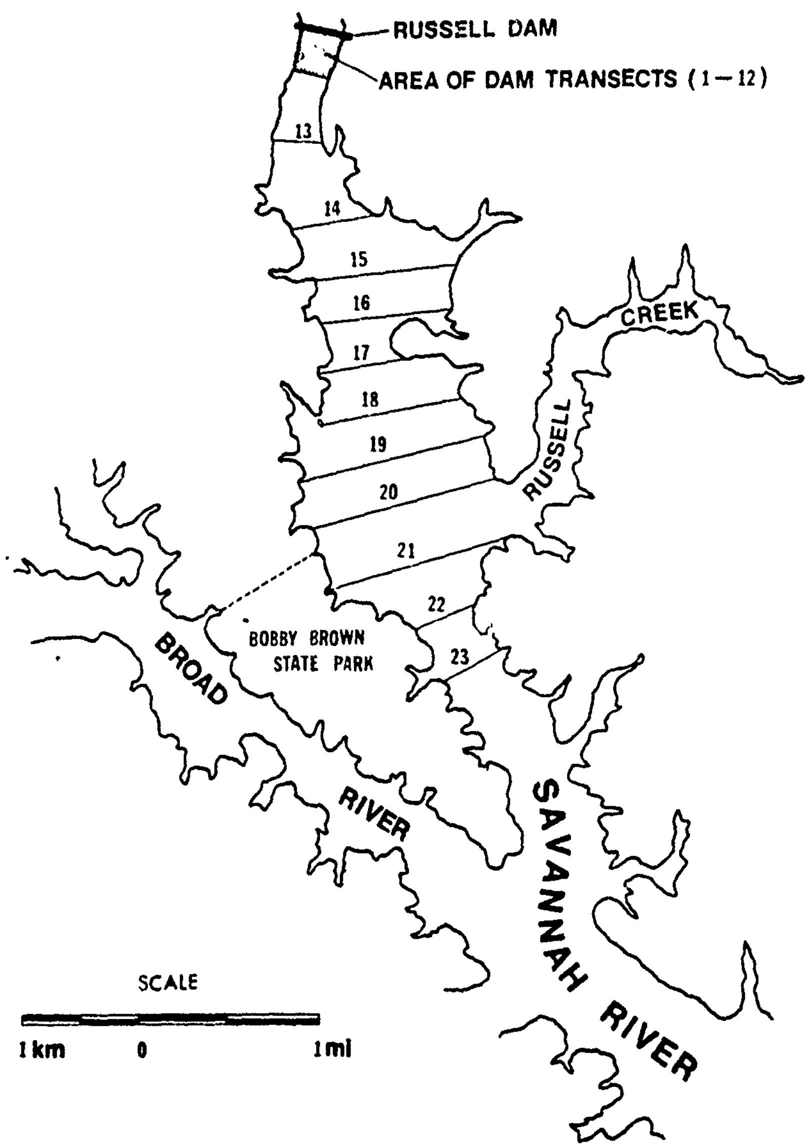


Figure 13. Savannah River arm of CHL below RBR Dam showing location of hydroacoustic transects

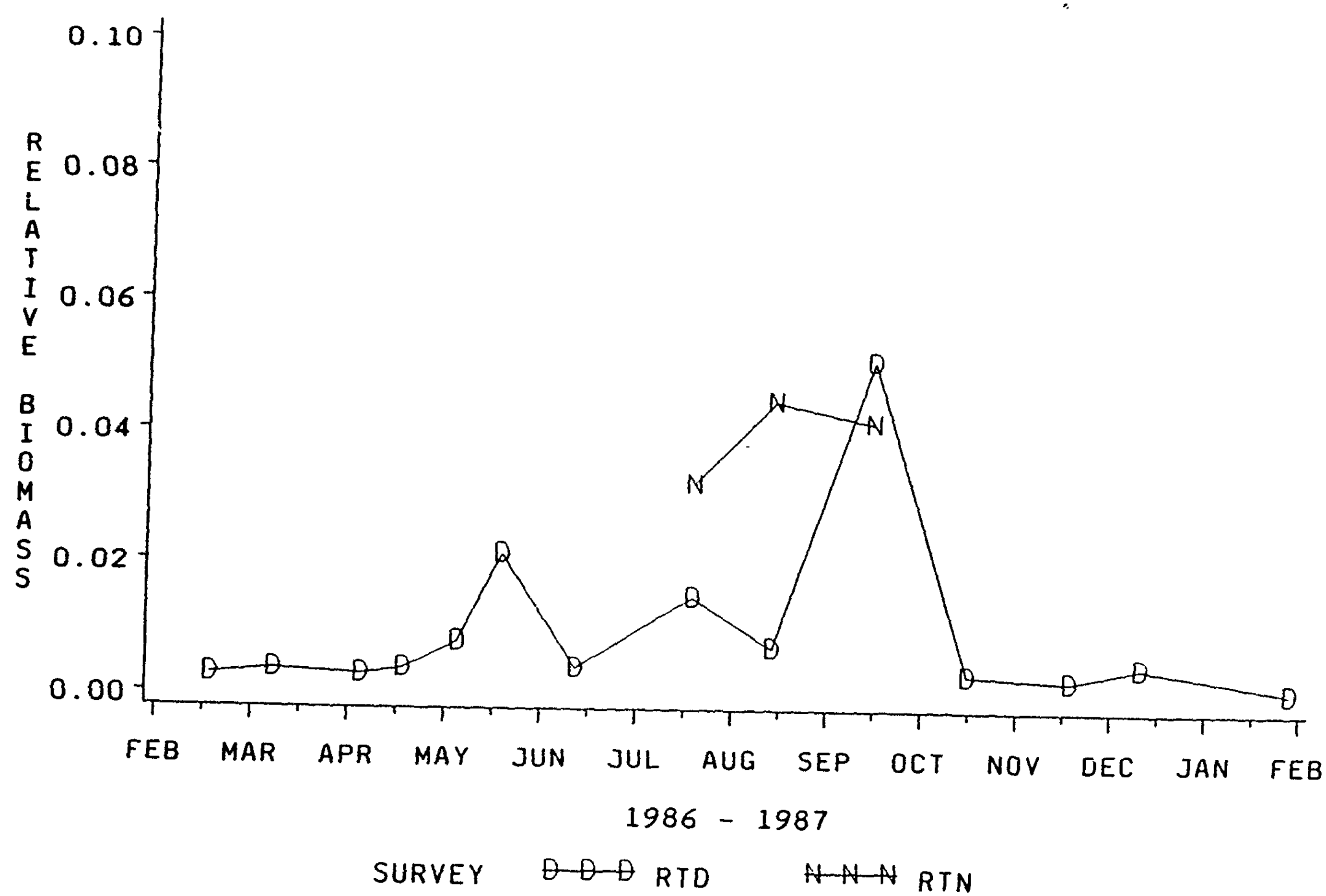


Figure 14. Relative fish biomass in Russell Tailwater during the day (RTD) and at night (RTN)

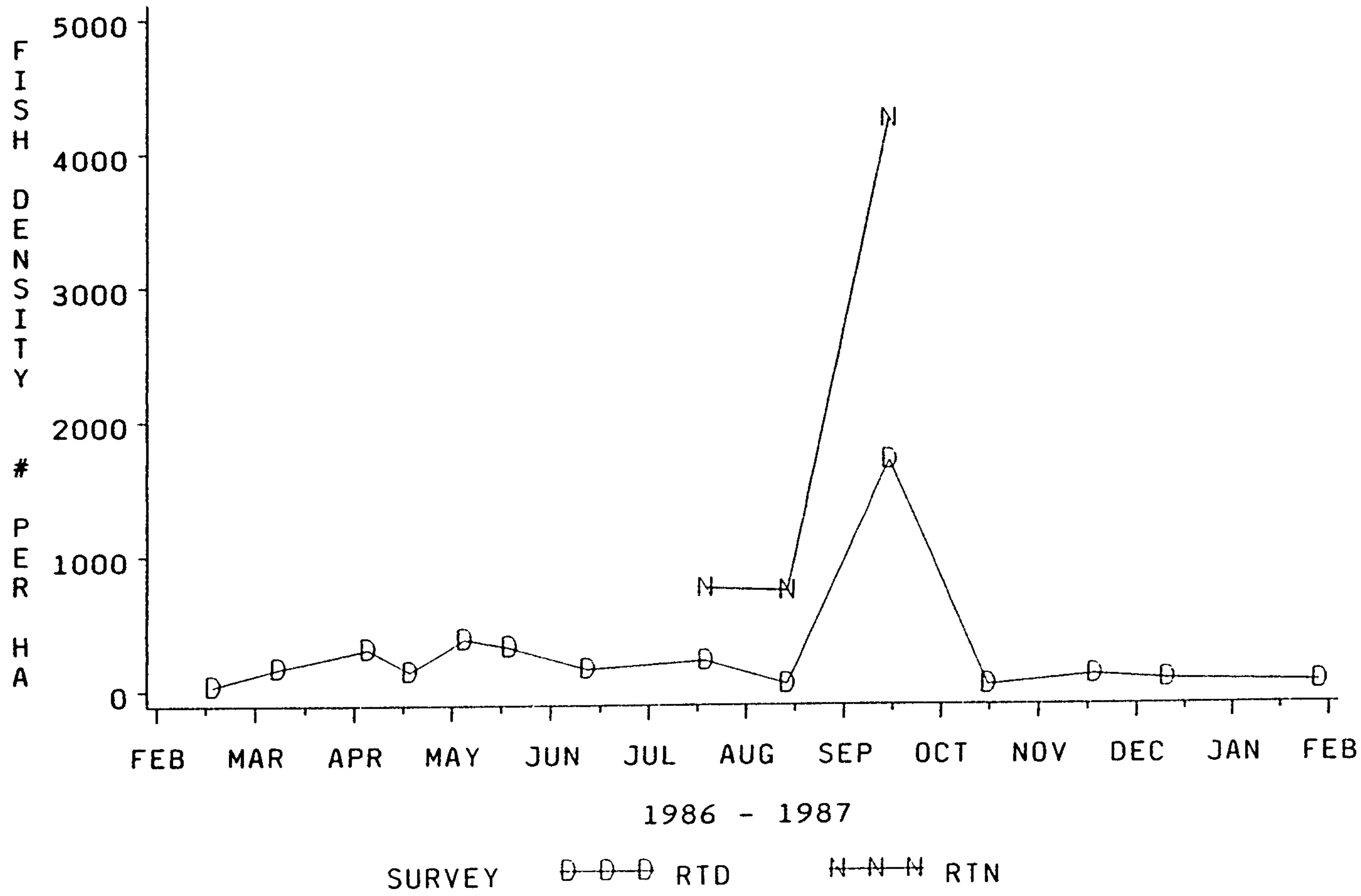


Figure 15. Fish density in Russell Tailwater during the day (RTD) and at night (RTN)

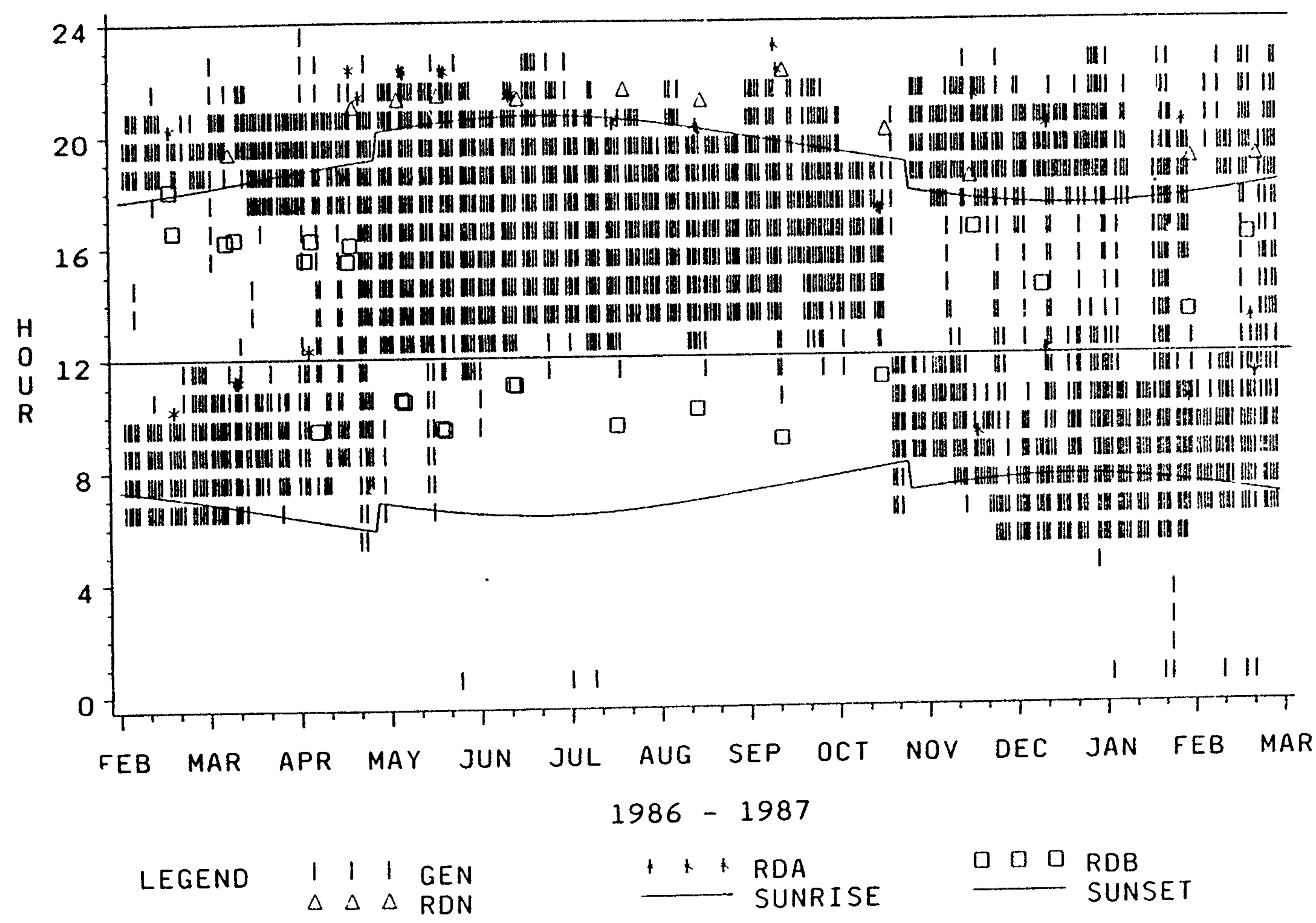


Figure 16. Russell Dam generating schedule and hydroacoustic sampling

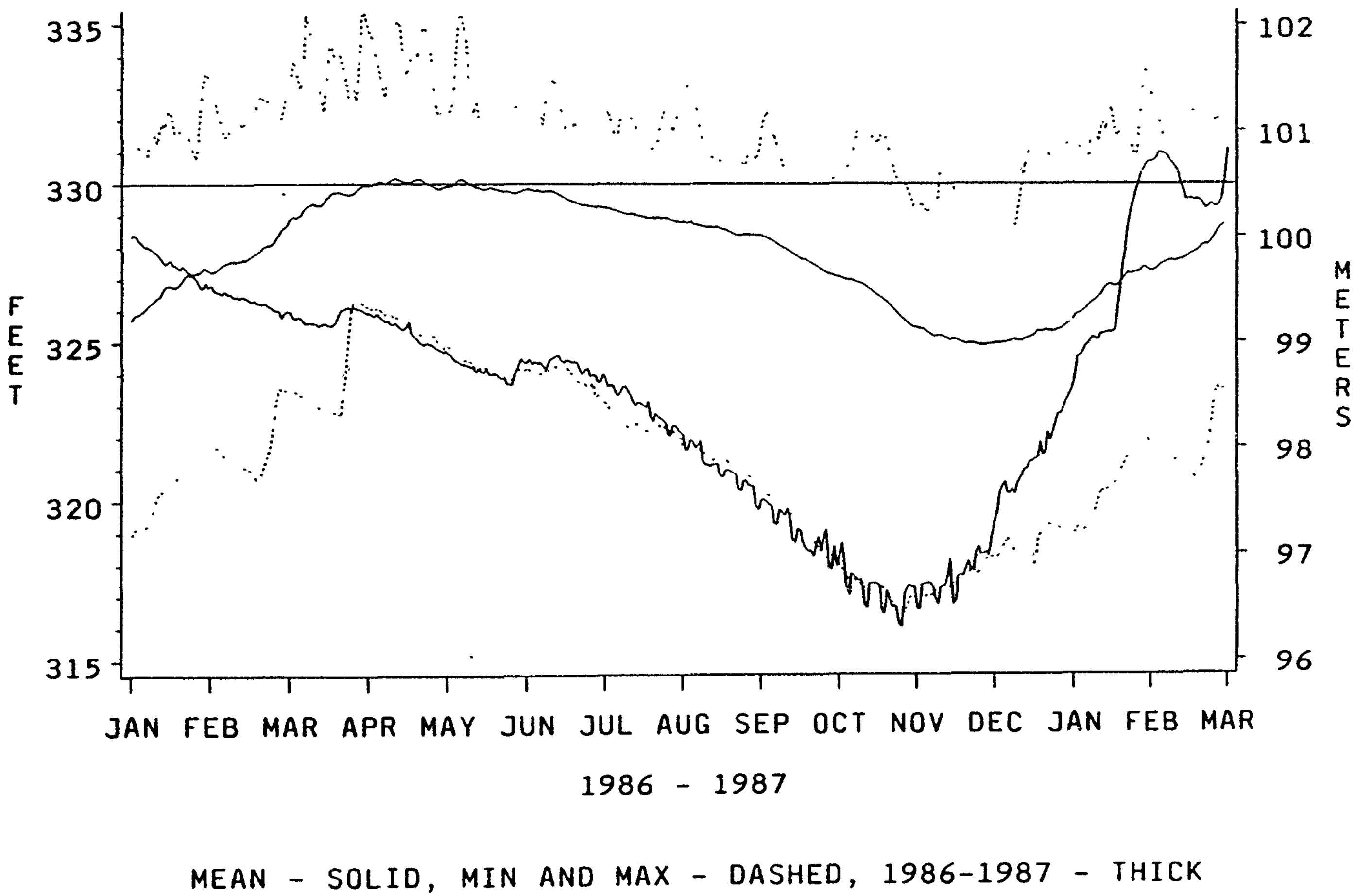


Figure 17. CHL elevation for 1986-1987 (lower solid line) in comparison with the 25-year average (upper solid line) and the historical minimum and maximum elevations for the last 25 years (dashed lines)

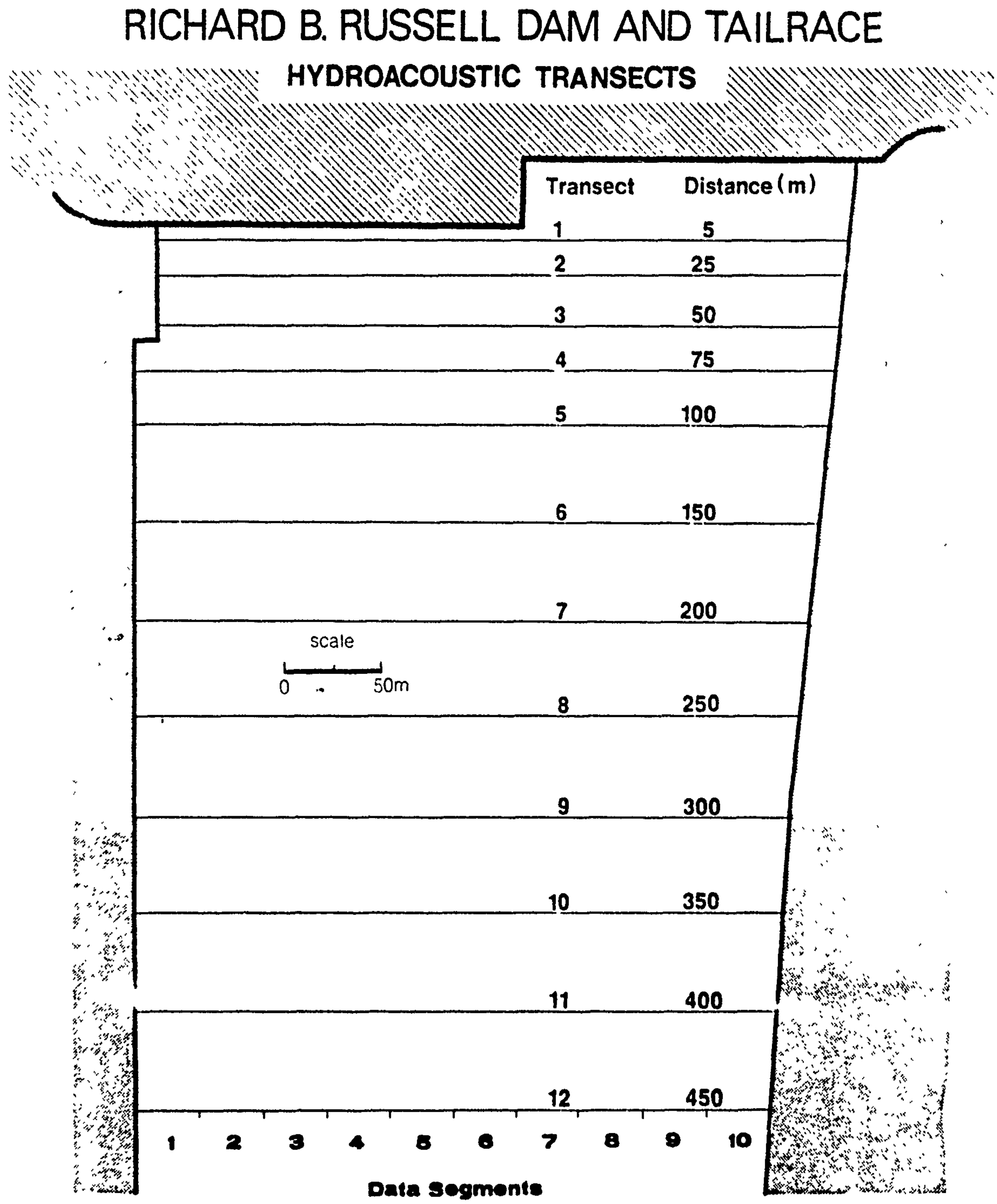


Figure 18. Diagram of Russell Dam and tailrace showing location of hydroacoustic survey transects

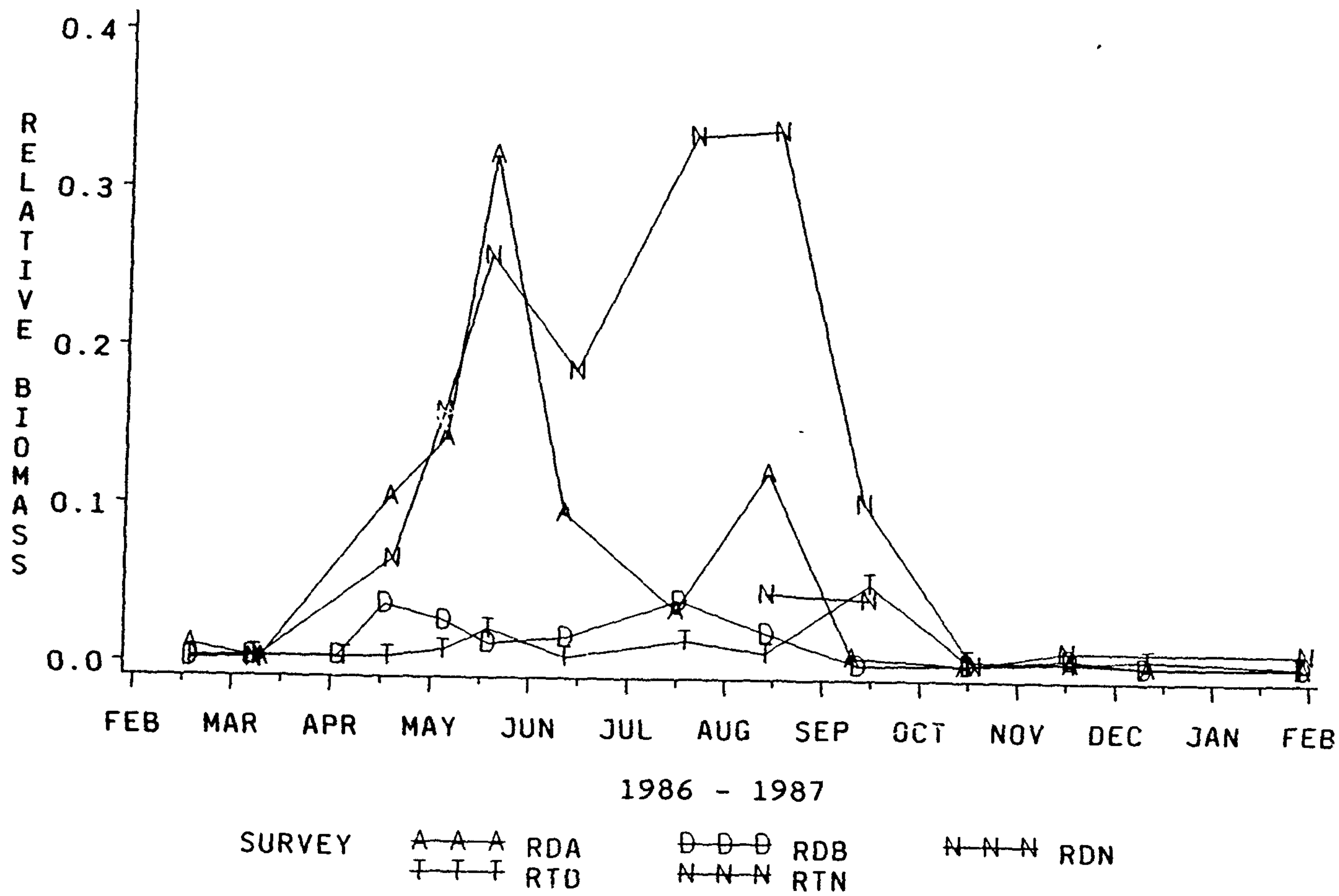


Figure 19. Relative fish biomass in Russell Tailwater during the day (RTD) and at night (RTN) as compared with RBR Dam surveys for pregeneration daytime periods (RDB), post-generation periods (RDA), and nongeneration periods at night (RDN)

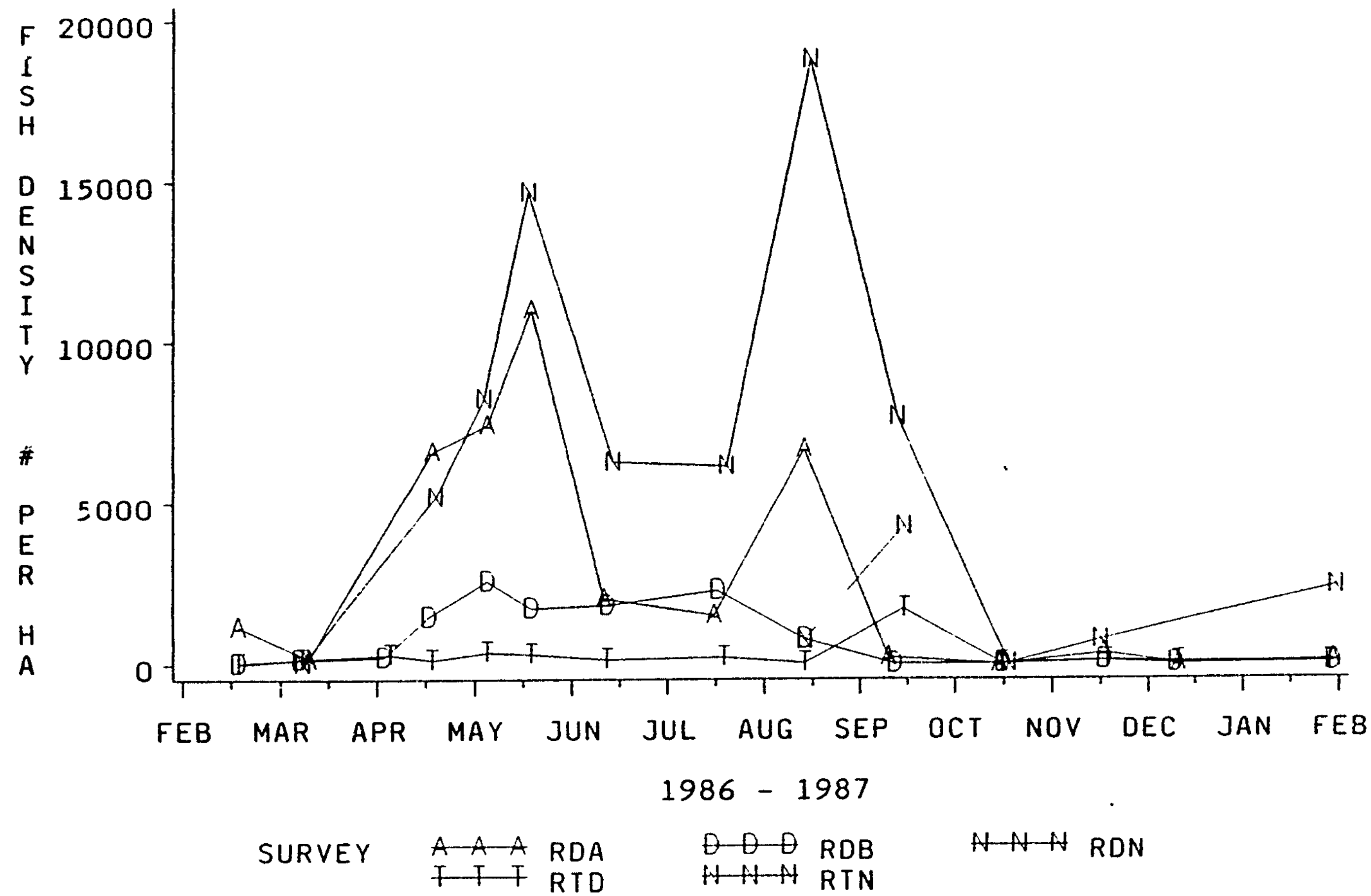


Figure 20. Fish density in Russell Tailwater during the day (RTD) and at night (RTN) as compared with RBR Dam surveys for pregeneration daytime periods (RDB), post-generation periods (RDA), and nongeneration periods at night (RDN)

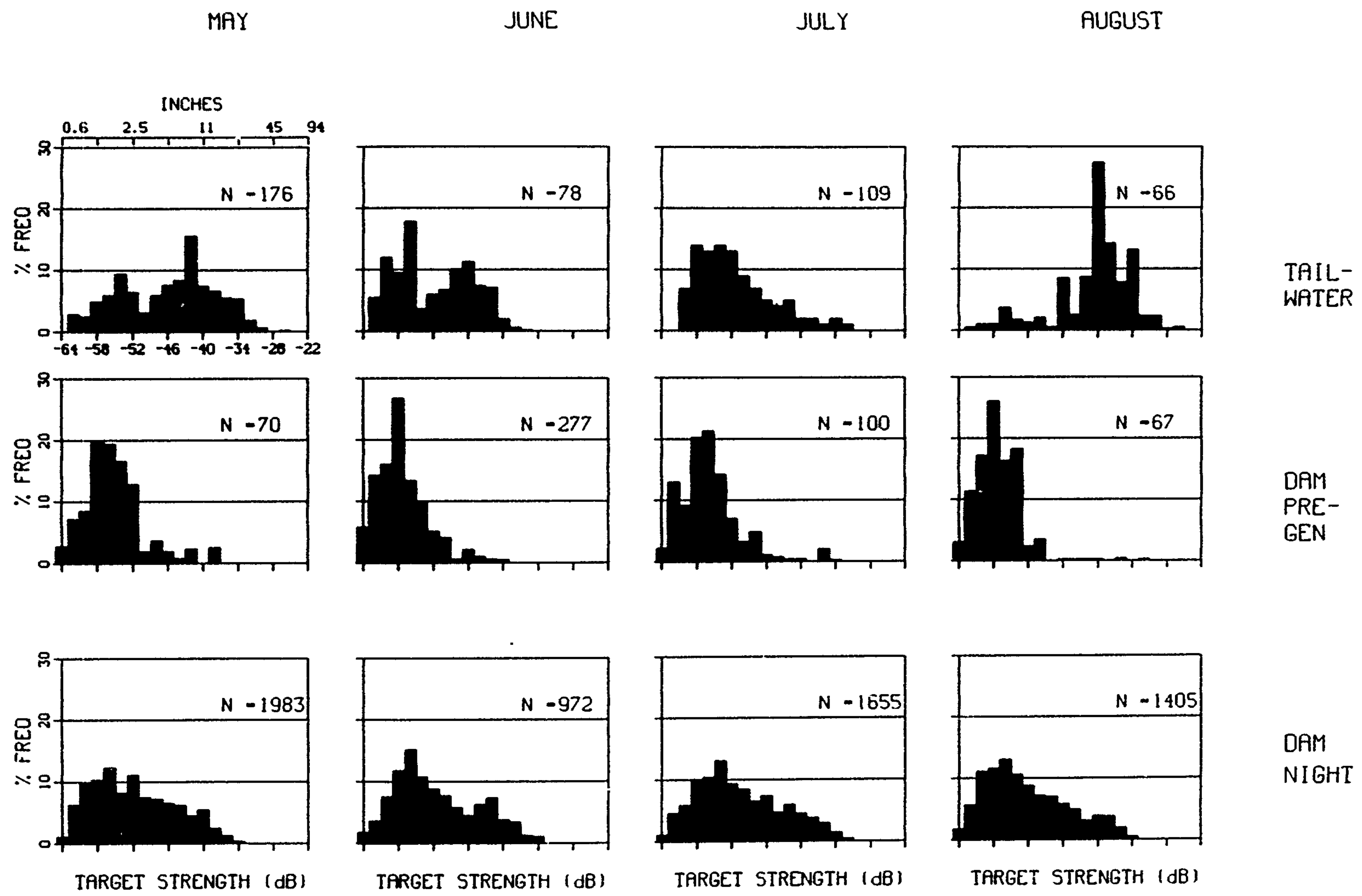


Figure 21. Distribution of acoustic size in the Russell Tailwater and at the RBR Dam during day (pregeneration) and at night for the summer of 1986

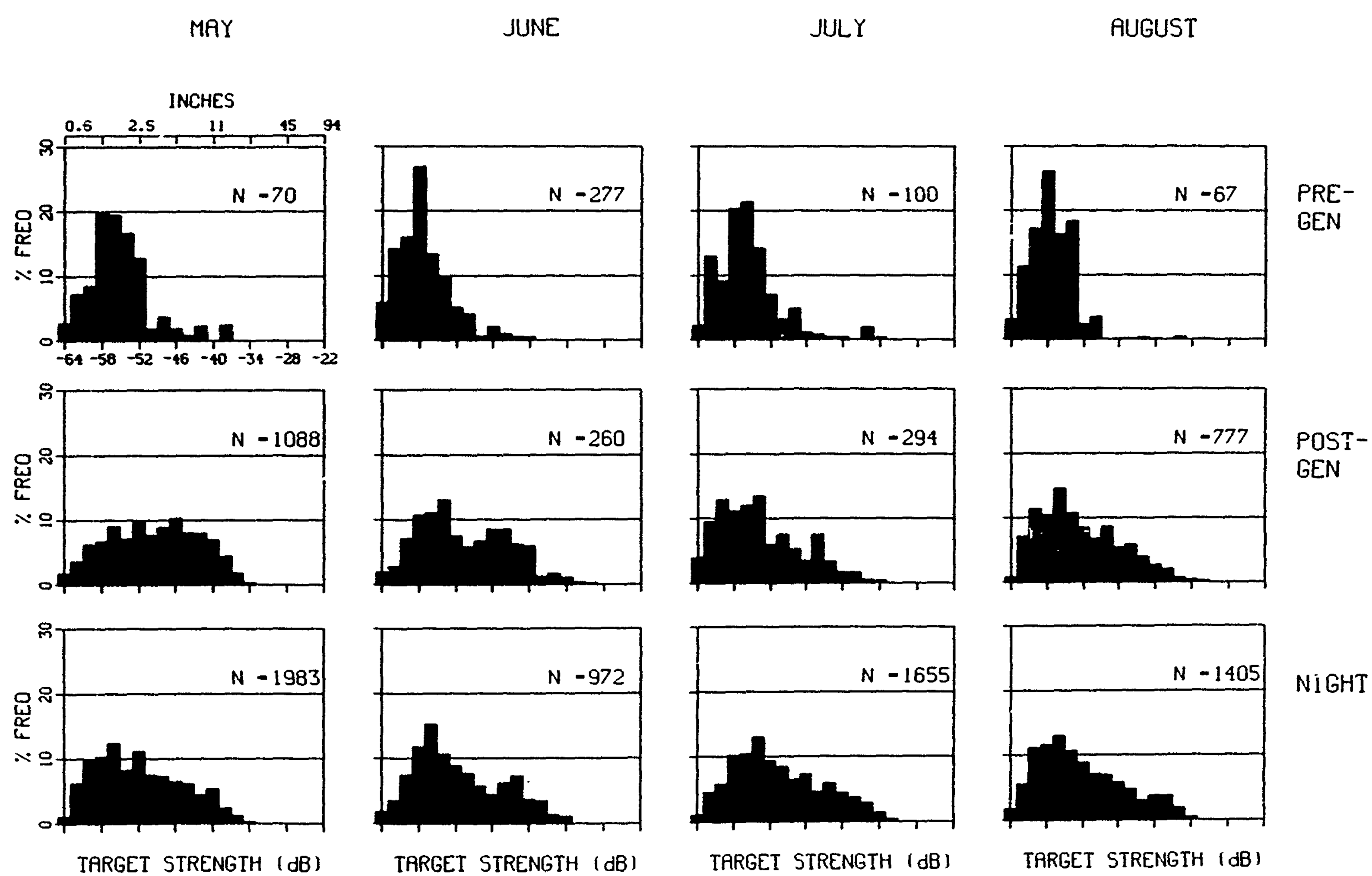


Figure 22. Distribution of acoustic size at the RBR Dam during the day pregeneration, immediately postgeneration, and at night during the summer of 1986

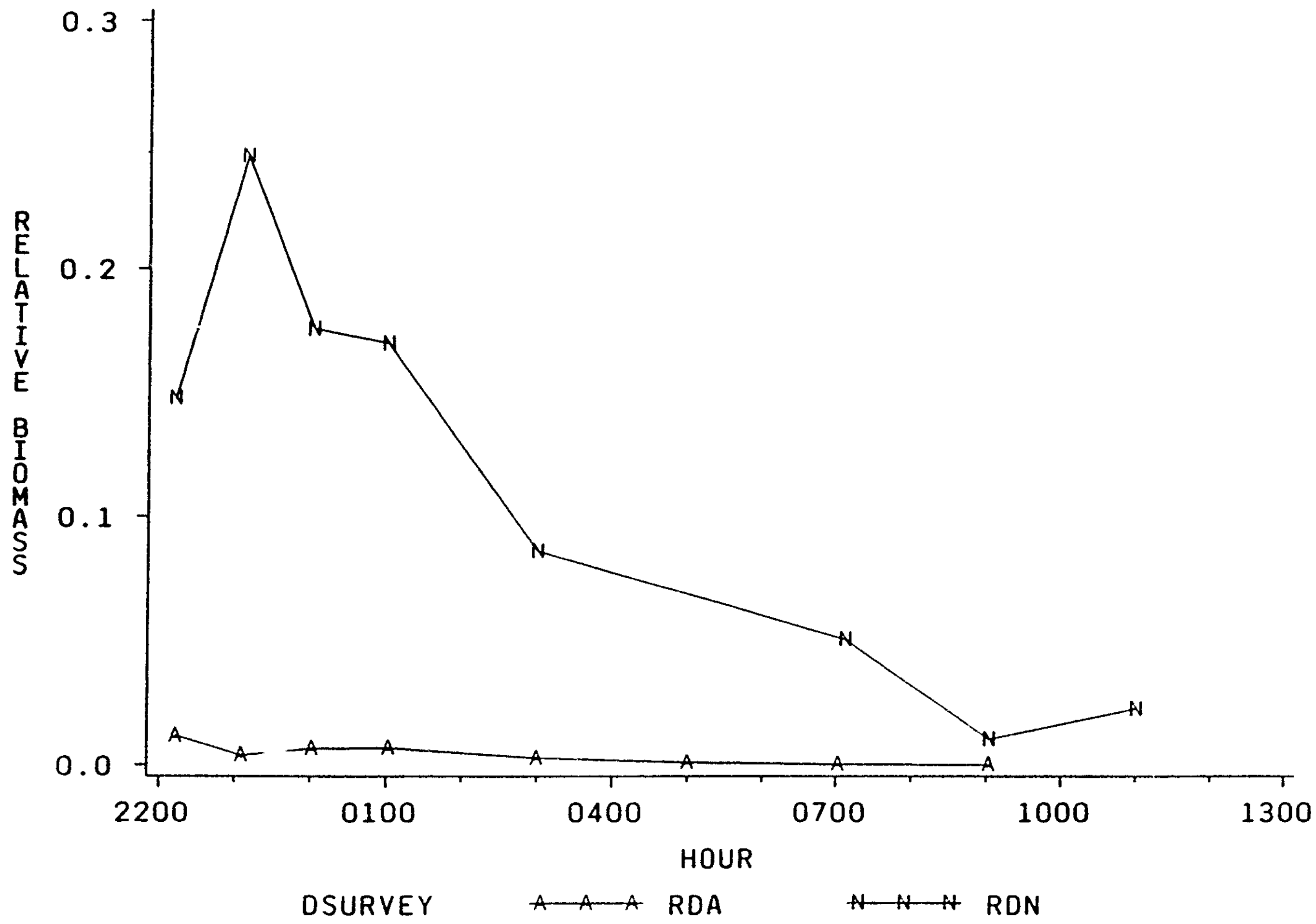


Figure 23. Change in relative biomass during diel surveys in September 1986; RDA survey started immediately after generation stopped and RDN survey started at night after a 26-hr generation moratorium

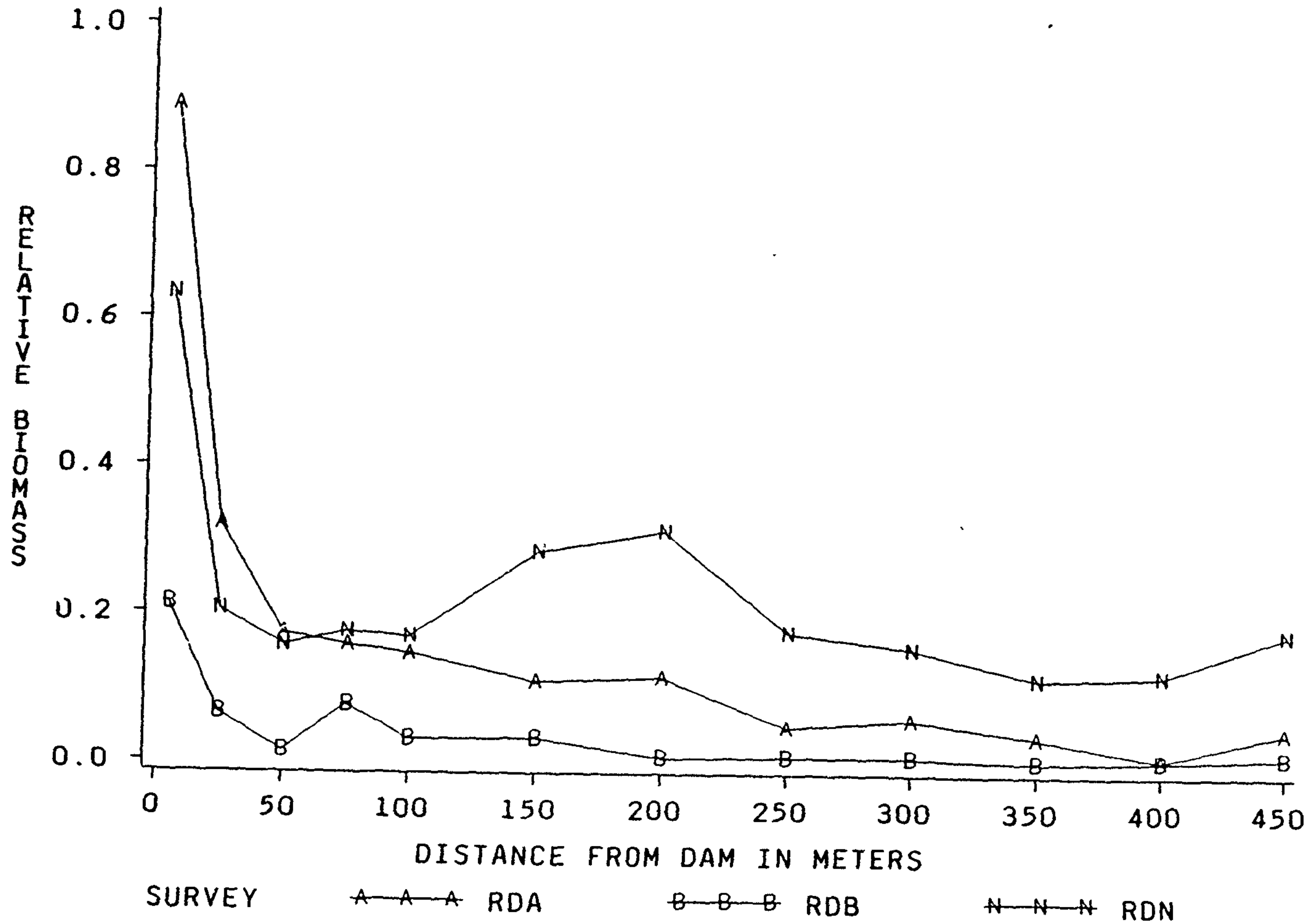


Figure 24. Distribution of relative fish biomass with distance from dam for pregeneration daytime periods (RDB), postgeneration periods (RDA), and nongeneration periods at night (RDN). Each point represents the arithmetic mean of surveys conducted from April through September 1986

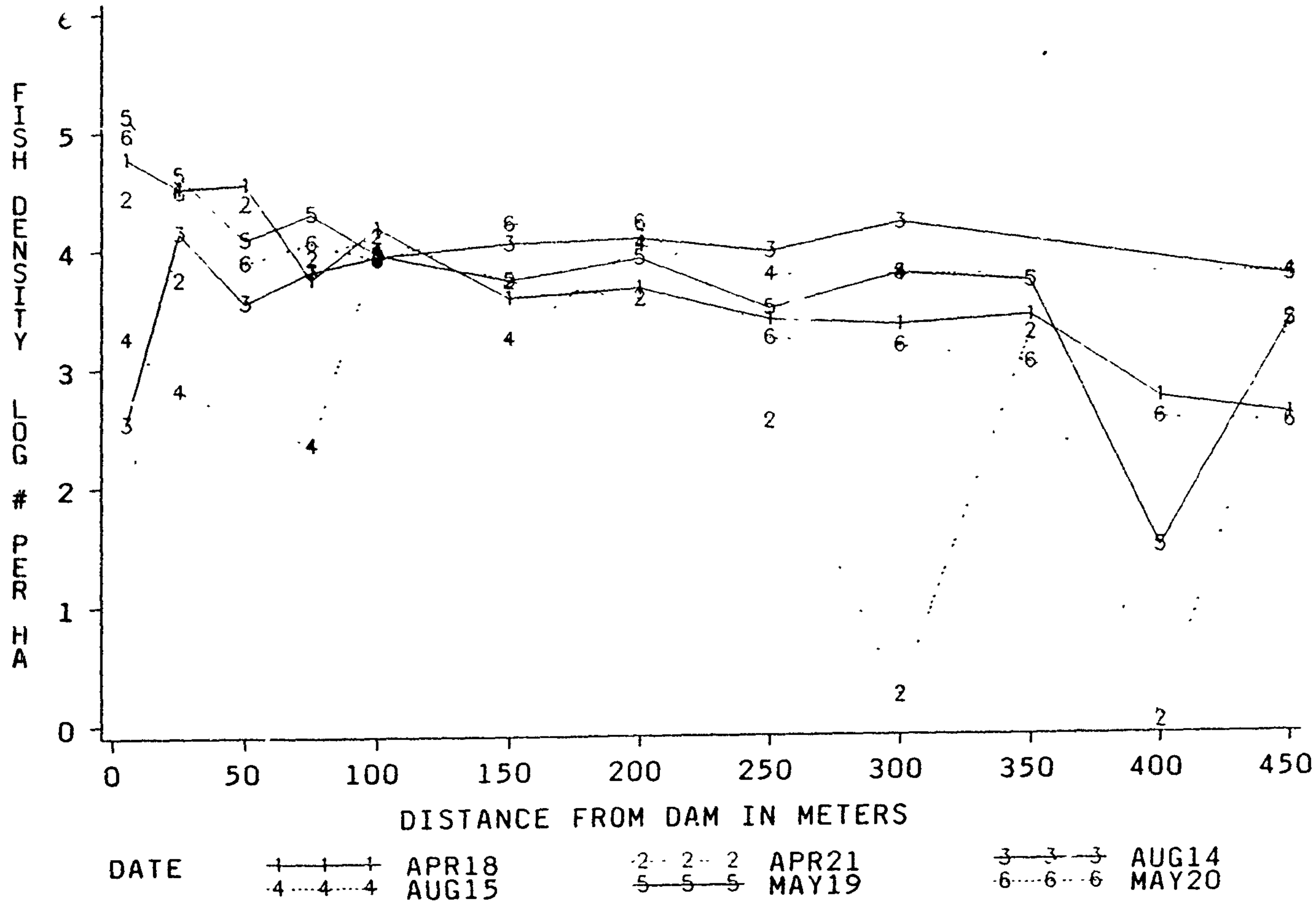


Figure 25. Distribution of fish density with distance from dam for three replicated replicated postgeneration periods in 1986. Note that density axis is a log scale due to the great range in numbers

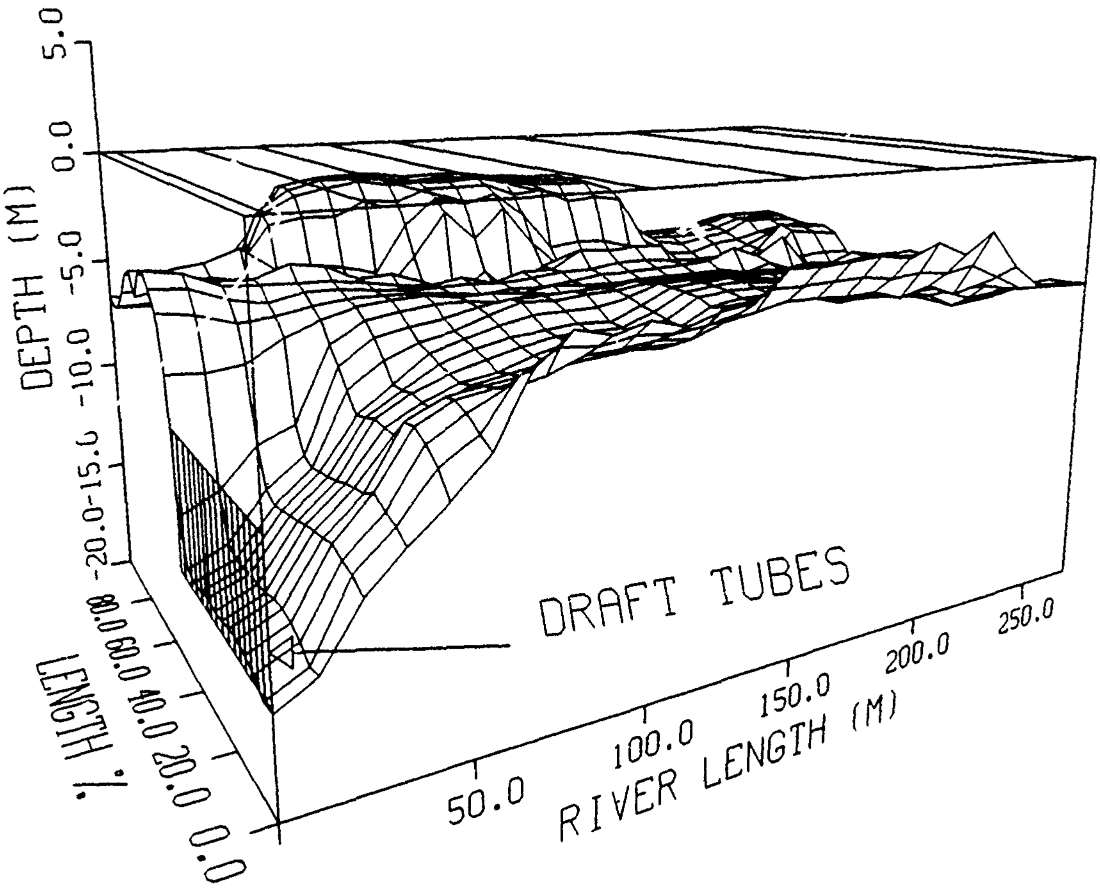


Figure 26. Three-dimensional representation of the Russell tailrace bathymetry; view is from the Georgia side of the project toward the South Carolina side where there is a shallow shoal area consisting of rocks and bouldᵔrs below the spillway. Horizontal lines in the plane of the surface indicate position of the first eight hydroacoustic survey transects; the last transect is just downstream of the buoy line

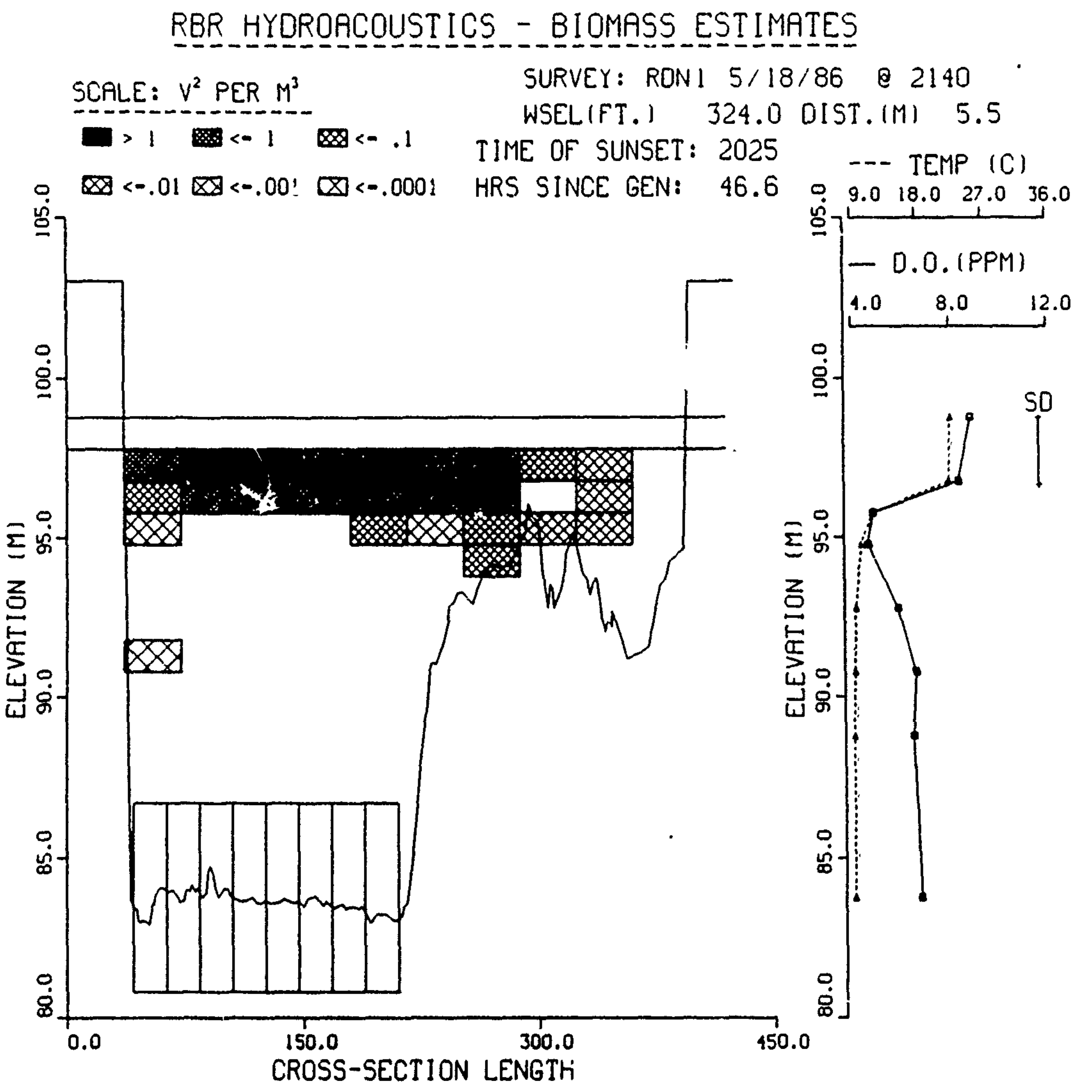


Figure 27. Distribution of relative fish biomass along Transect 1 on 18 May 1986 at night. Temperature and dissolved oxygen profile shown to the right

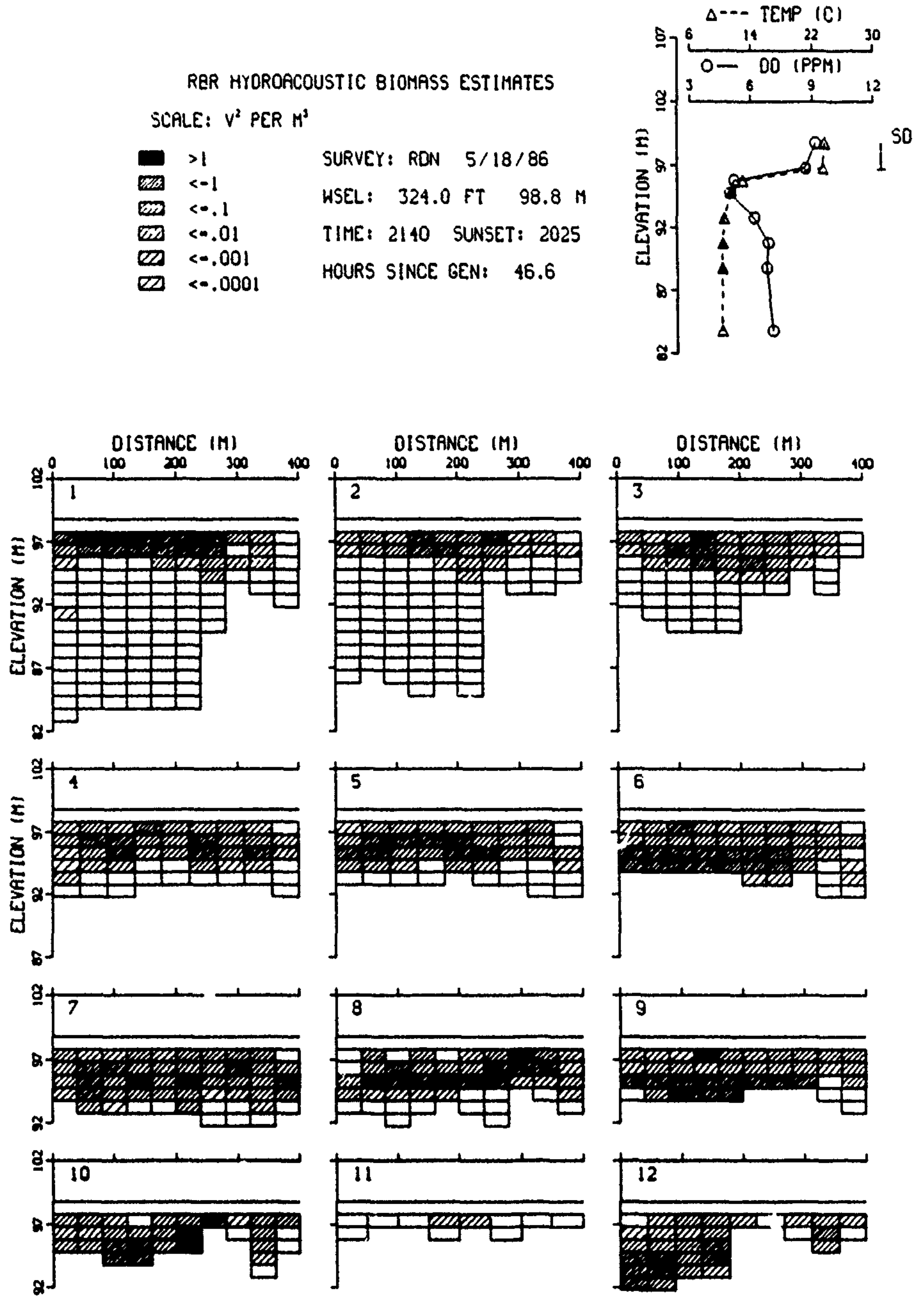


Figure 28. Distribution of relative fish biomass for Transects 1-12 on 18 May 1986 at night, after no generation. Temperature and dissolved oxygen profiles and Secchi disk depth are provided in the subfigure at top right of figure. Additional information provided includes water surface elevation (WSEL) in both feet and metres, time (TIME) at the beginning of the survey, time of sunset (SUNSET) for the day of the survey, and the number of hours since the cessation of generation (HOURS SINCE GEN)

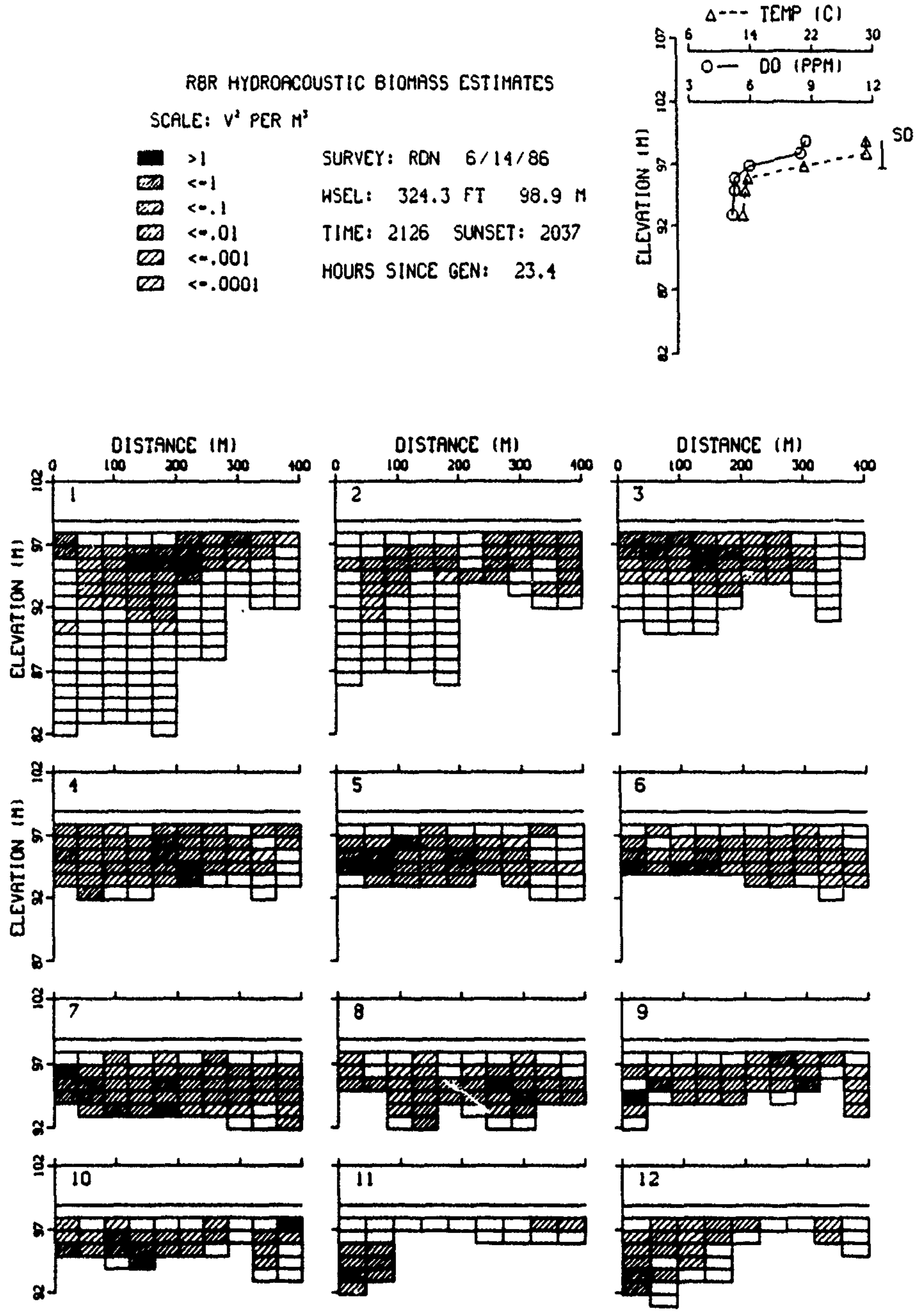


Figure 29. Distribution of relative fish biomass on 14 June 1986 at night after no generation. (Refer to Figure 28 for explanation of data)

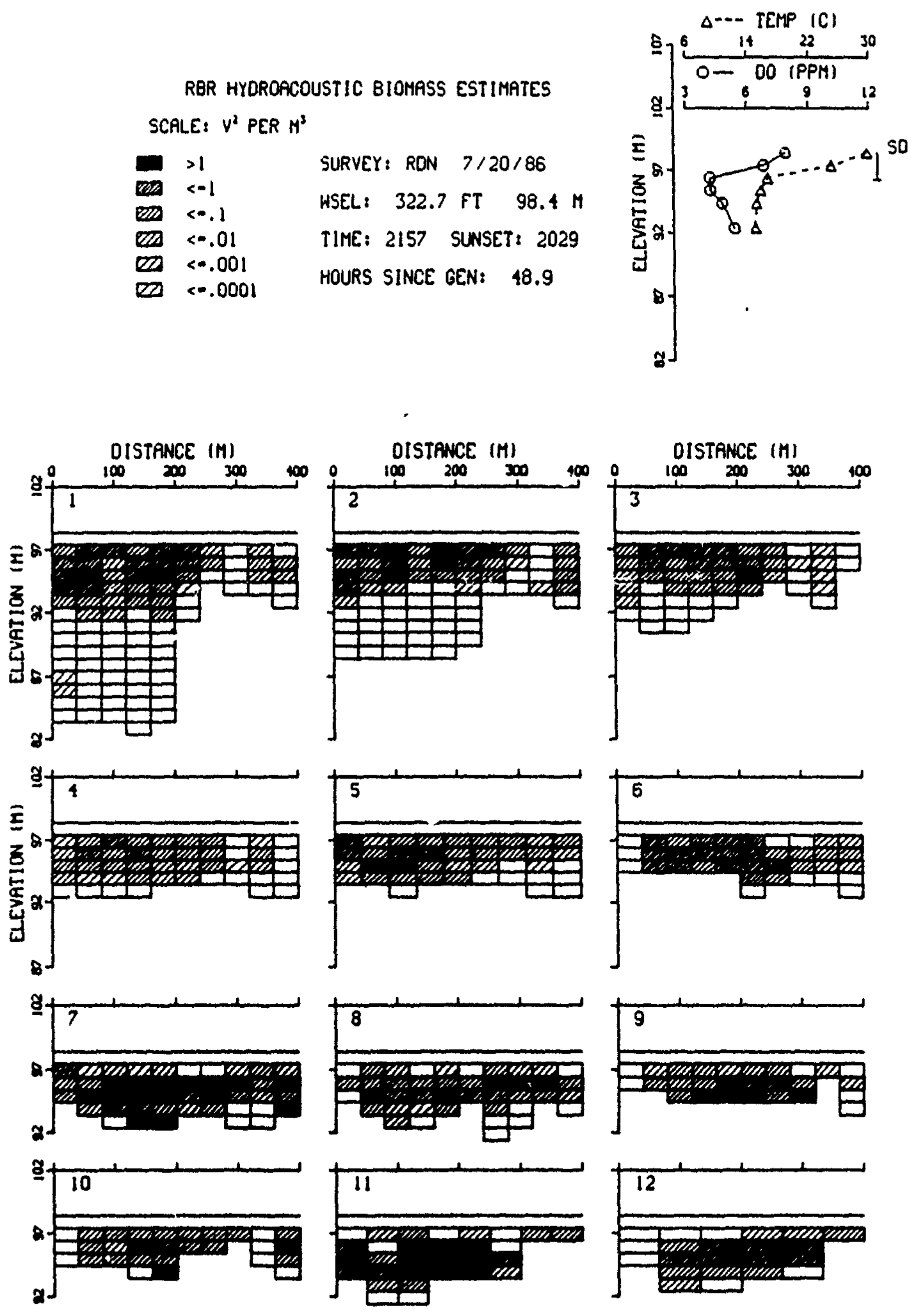


Figure 30. Distribution of relative fish biomass on 20 June 1986 at night after n^ generation. (Refer to Figure 28 for explanation of data)

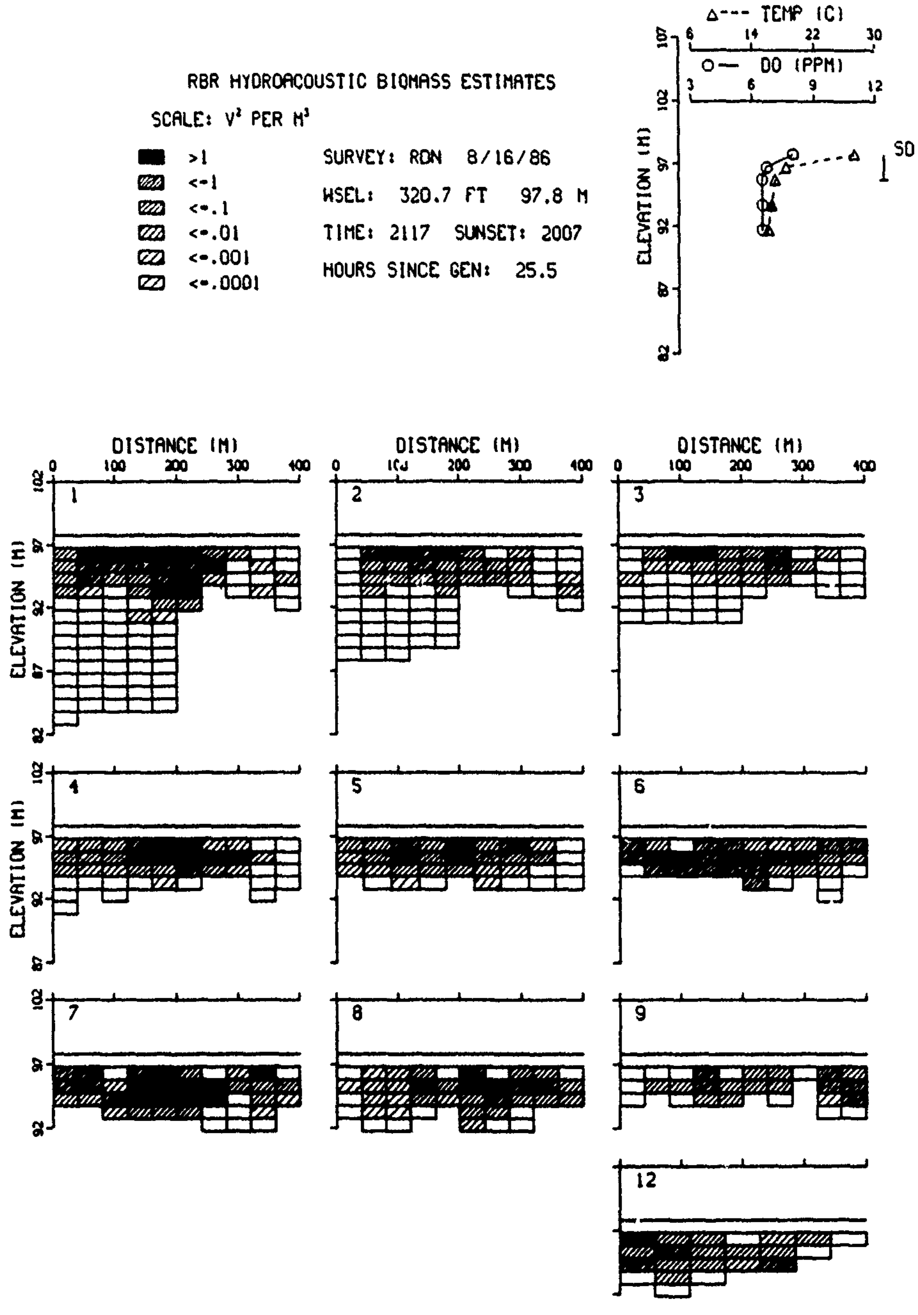


Figure 31. Distribution of relative fish biomass on 16 August 1986 at night after no generation. (Refer to Figure 28 for explanation of data)

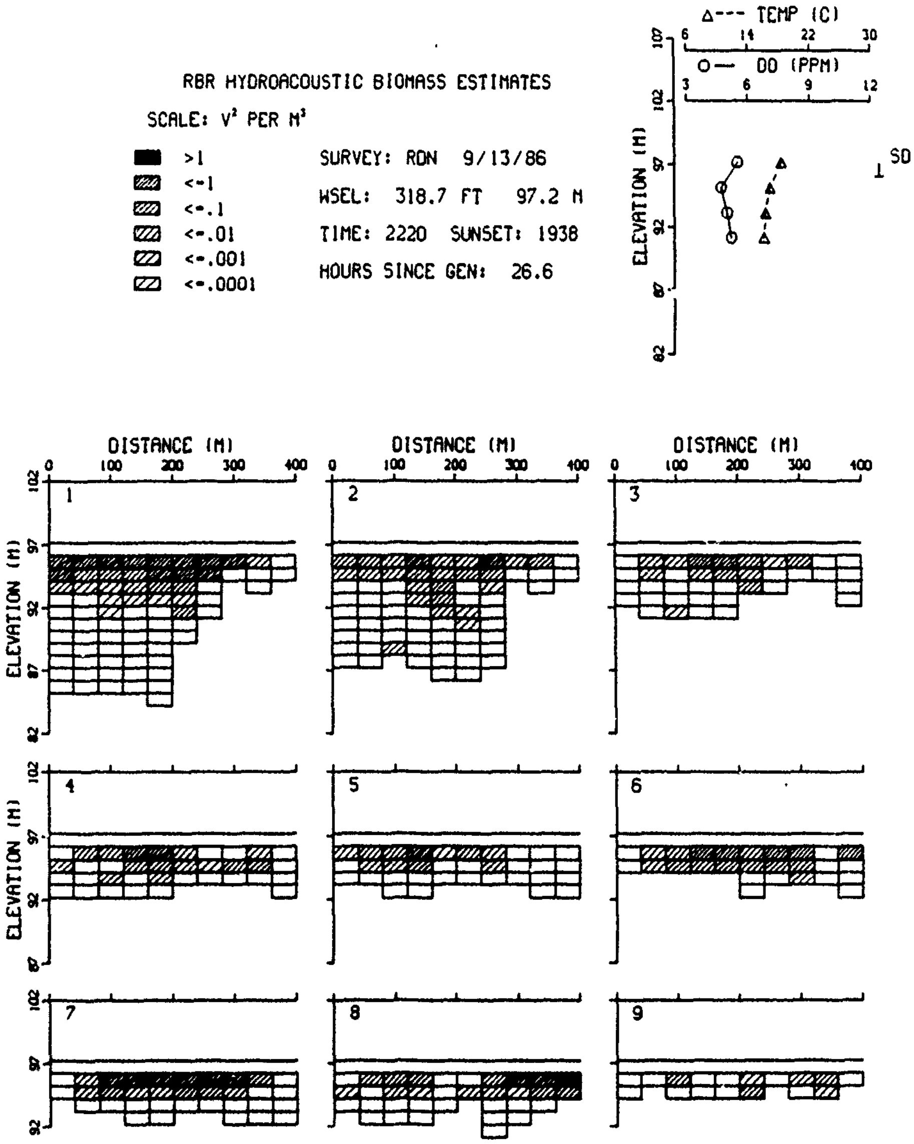


Figure 32. Distribution of relative fish biomass on 13 September 1986 at night after no generation. (Refer to Figure 28 for explanation of data)

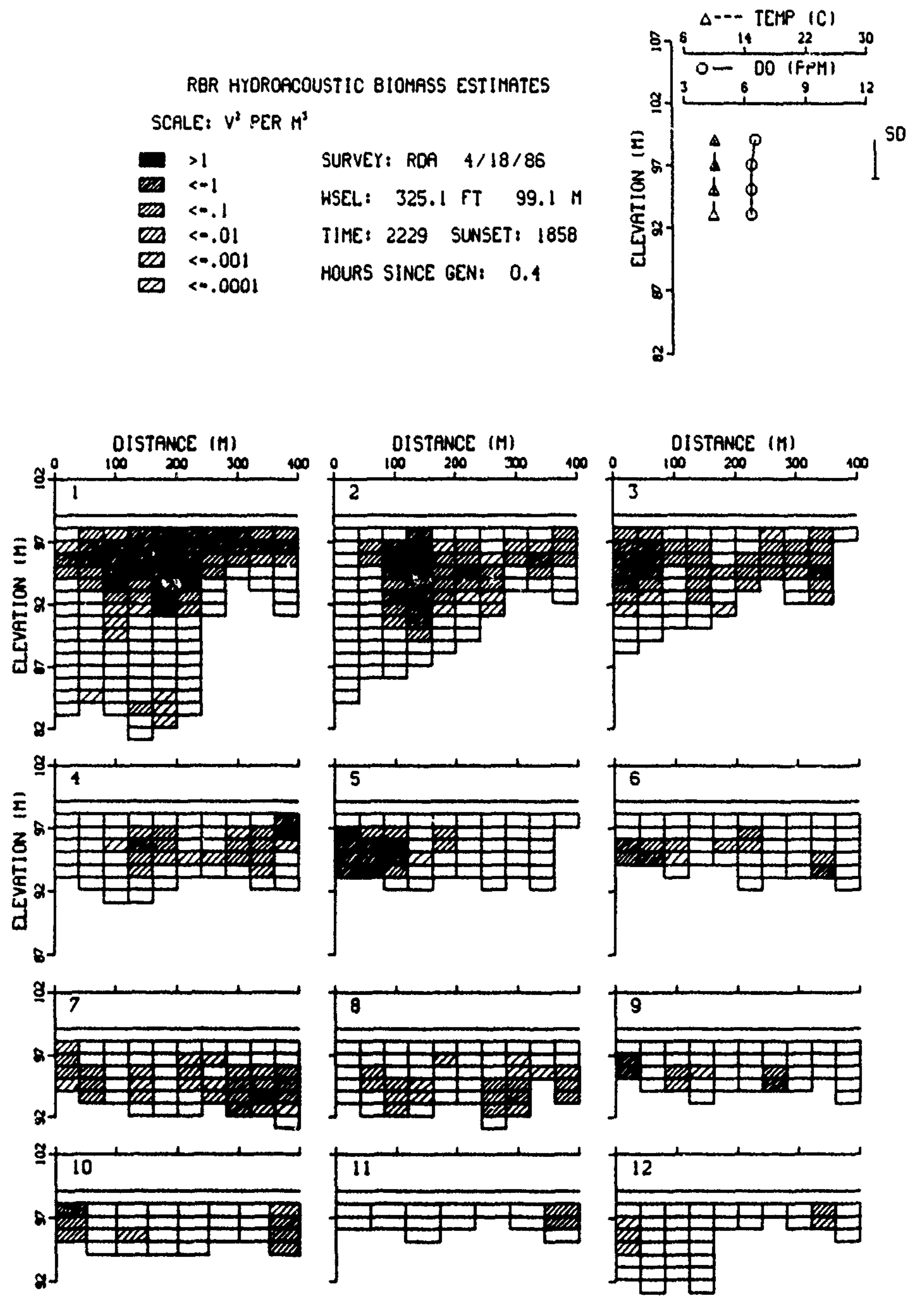


Figure 33. Distribution of relative fish biomass on 18 April 1986 at night immediately after generation. (Refer to Figure 28 for explanation of data)

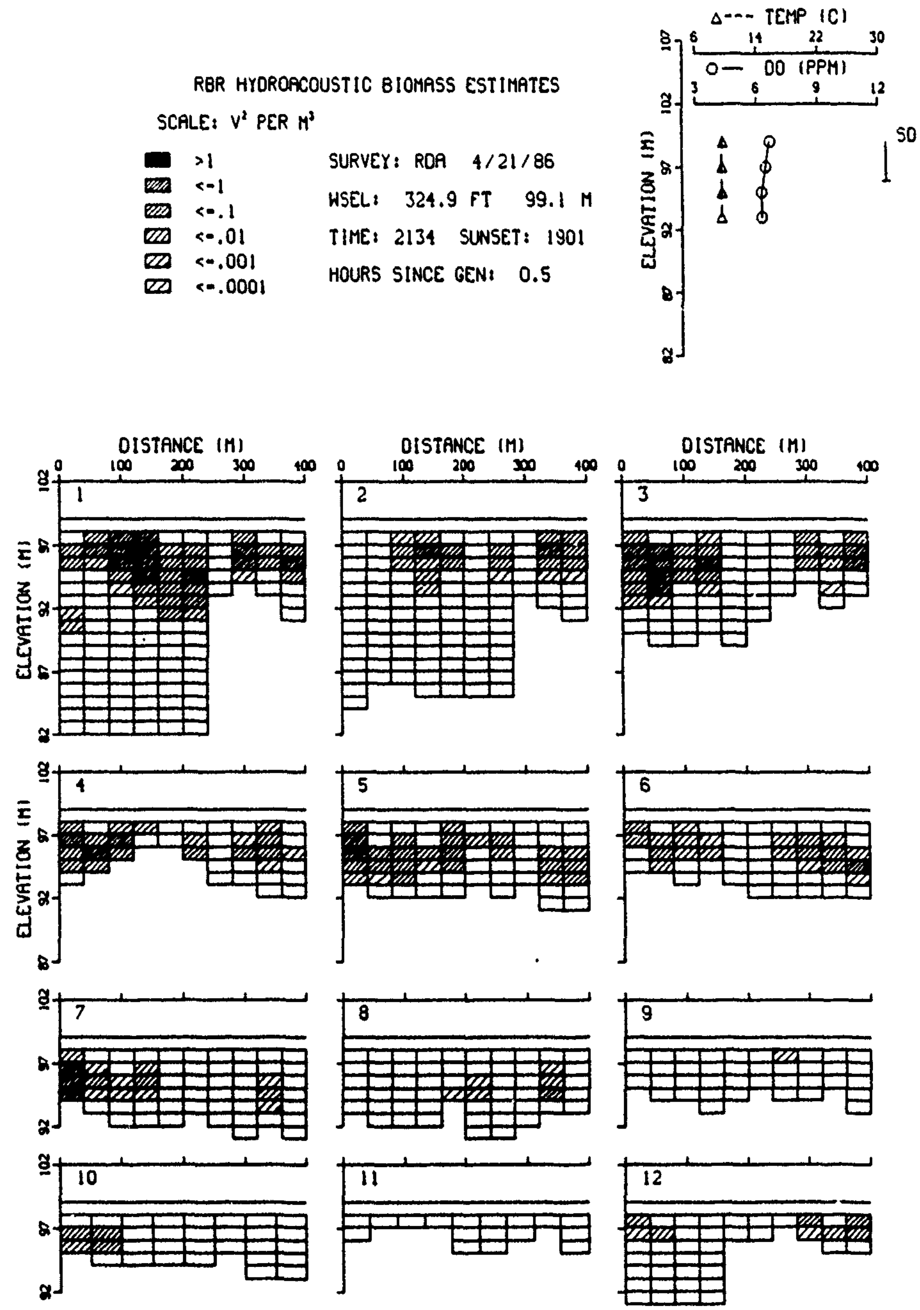


Figure 34. Distribution of relative fish biomass on 21 April 1986 at night immediately after generation. (Refer to Figure 28 for explanation of data)

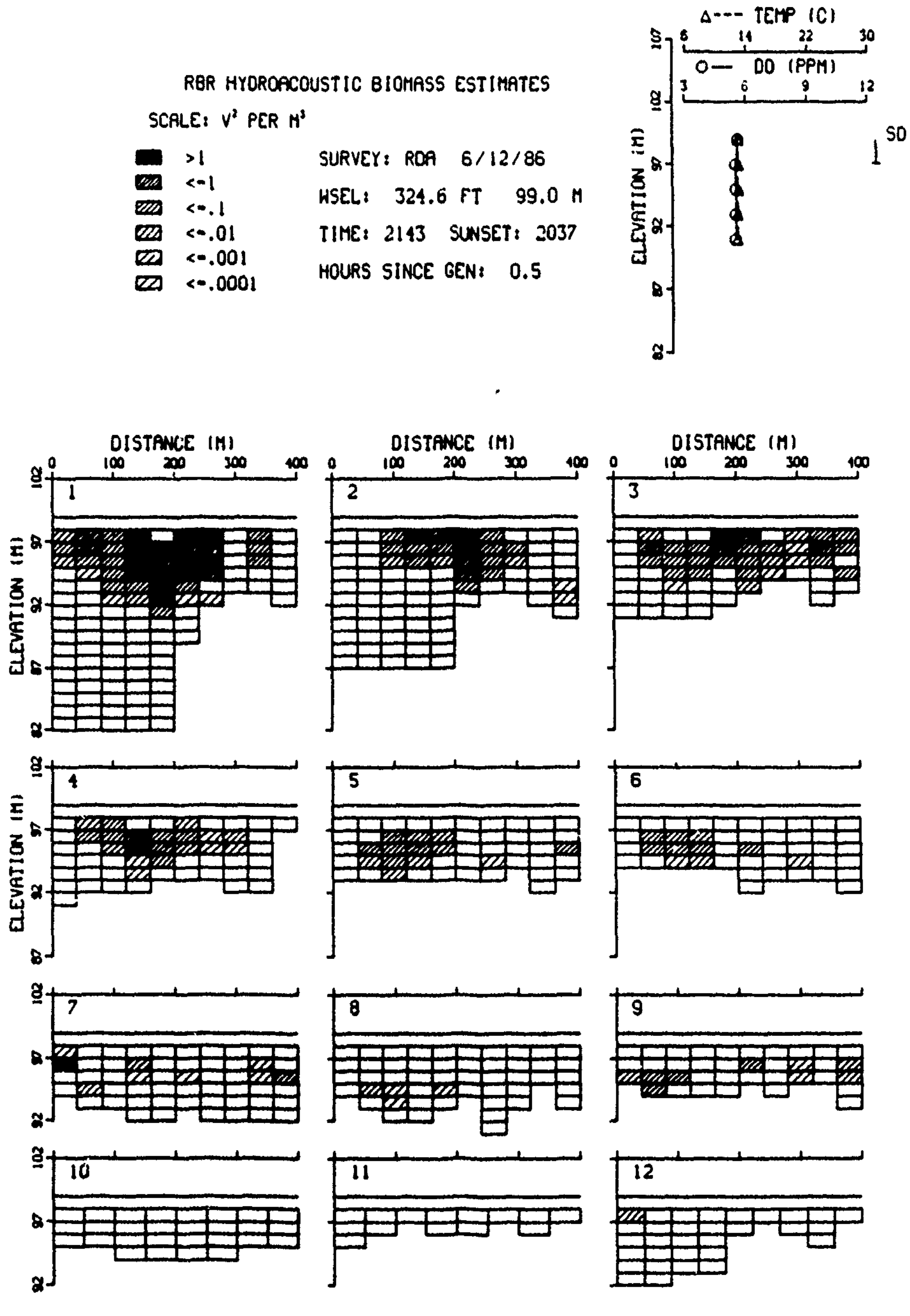


Figure 35. Distribution of relative fish biomass on 12 June 1986 at night immediately after generation. (Refer to Figure 28 for explanation of data)

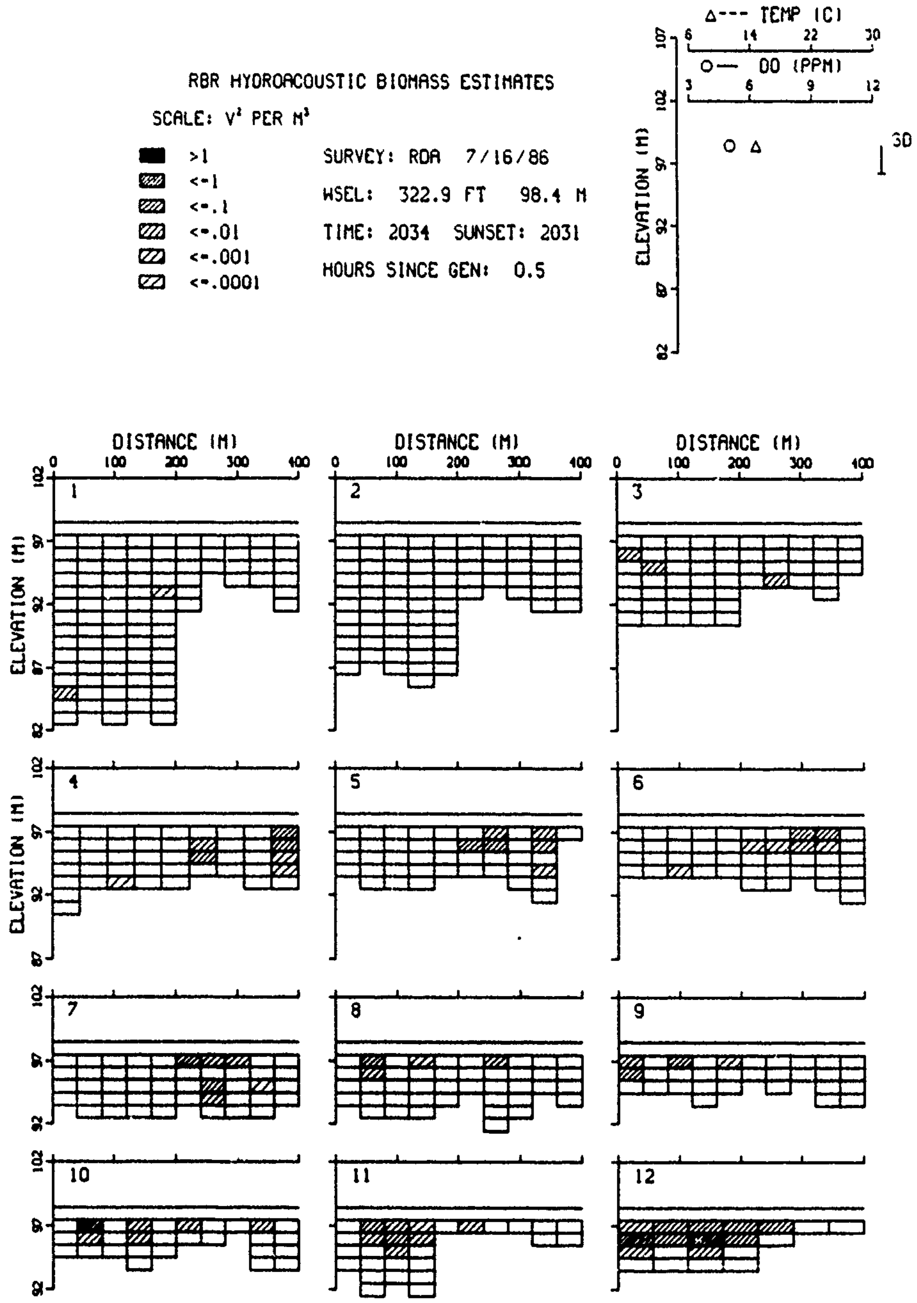


Figure 36. Distribution of relative fish biomass on 16 July 1986 at dusk immediately after generation. (Refer to Figure 28 for explanation of data)

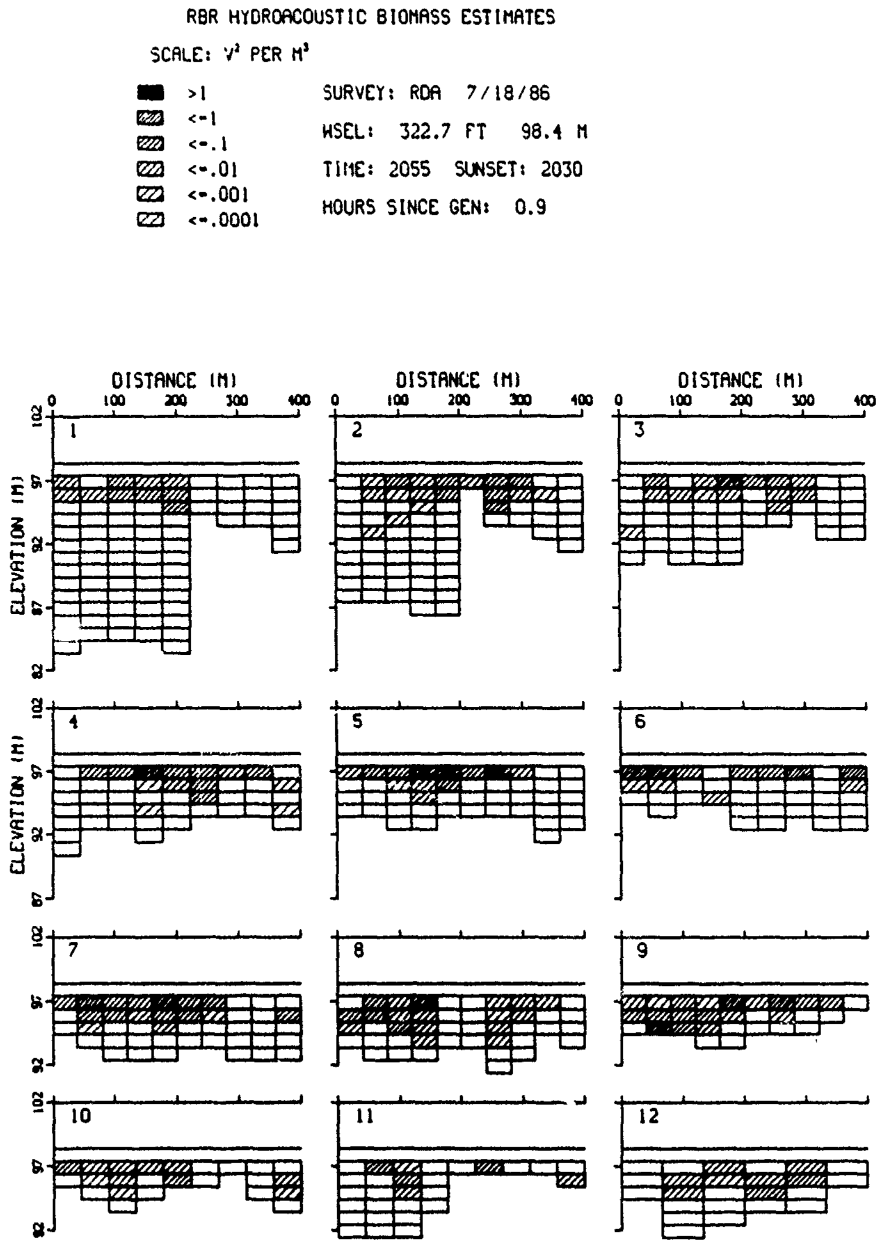


Figure 37. Distribution of relative fish biomass on 18 July 1986 at dusk immediately after generation. (Refer to Figure 28 for explanation of data)

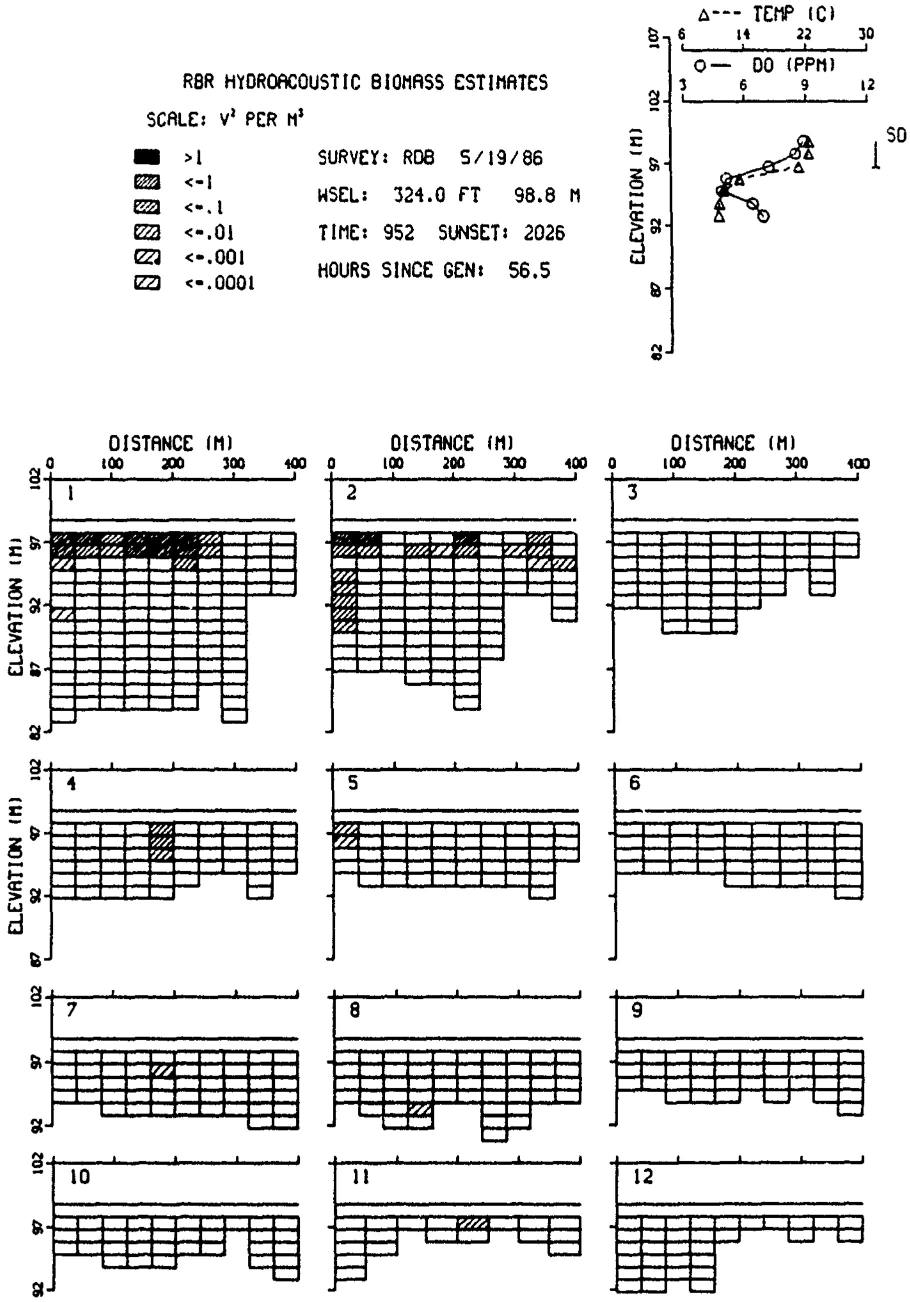


Figure 38. Distribution of relative fish biomass on 19 May 1986 during the day after no generation. (Refer to Figure 28 for explanation of data)

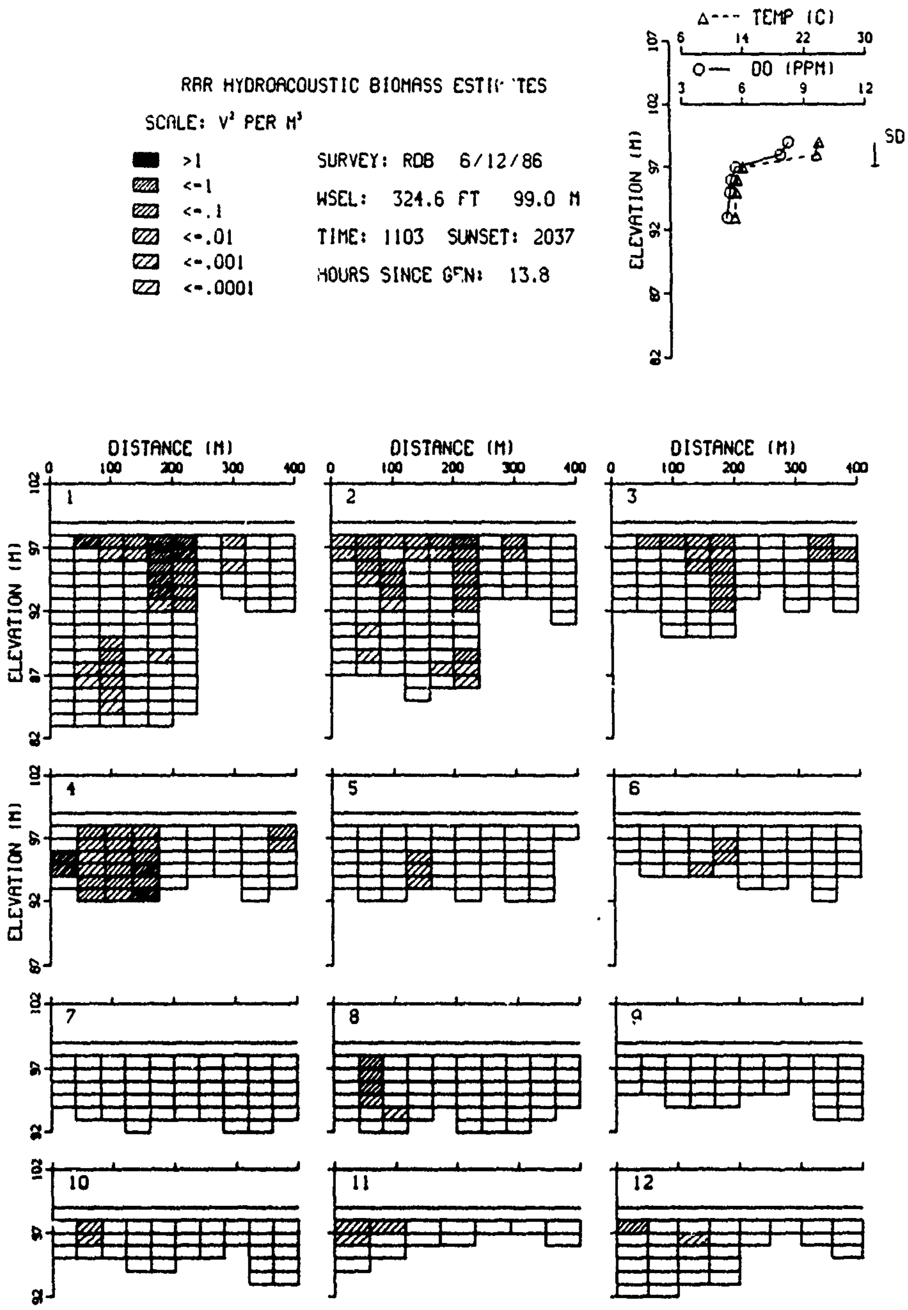


Figure 39. Distribution of relative fish biomass on 12 June 1986 during the day after no generation. (Refer to Figure 28 for explanation of data)

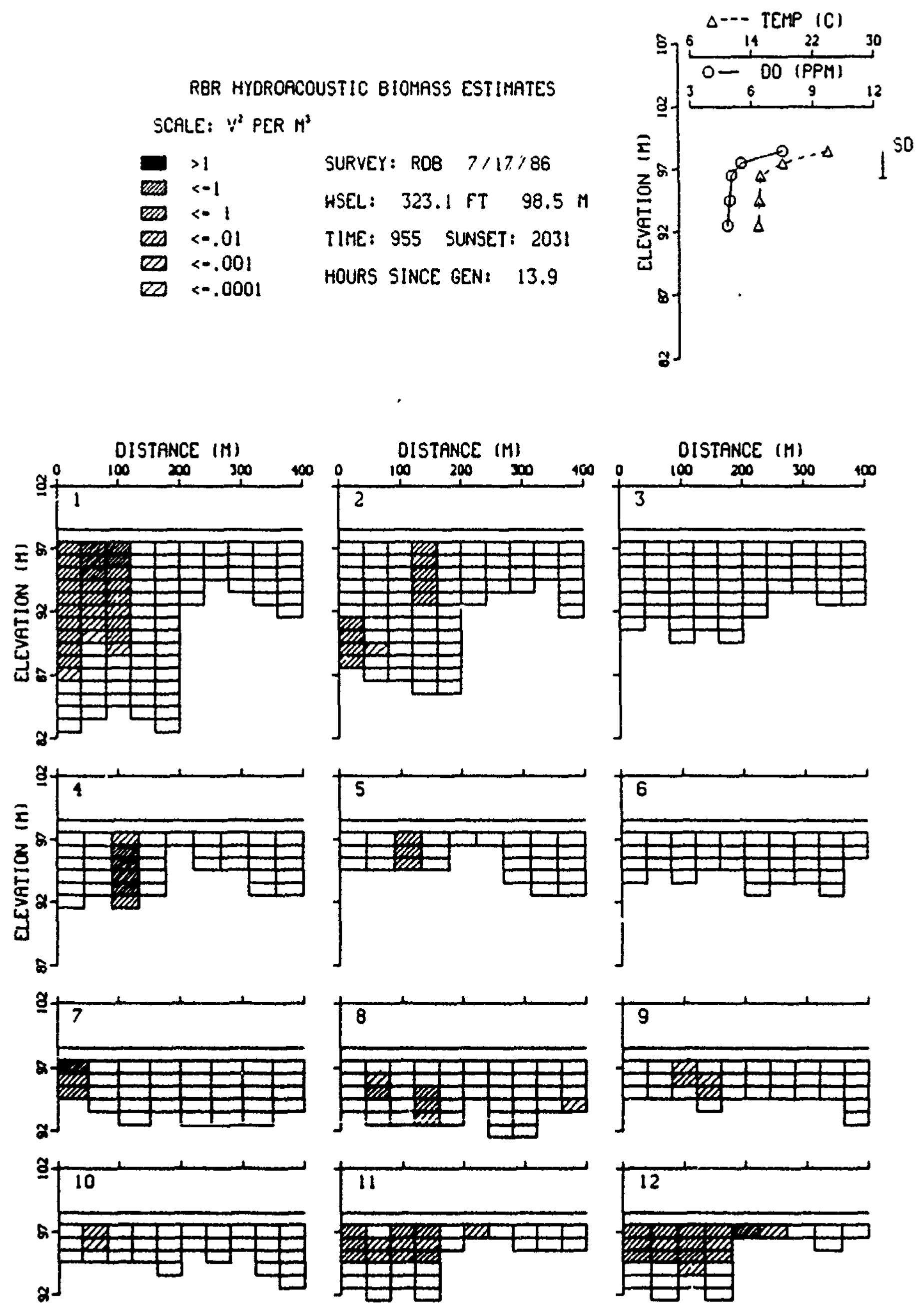


Figure 40. Distribution of relative fish biomass on 17 July 1986 during the day after no generation. (Refer to Figure 28 for explanation of data)

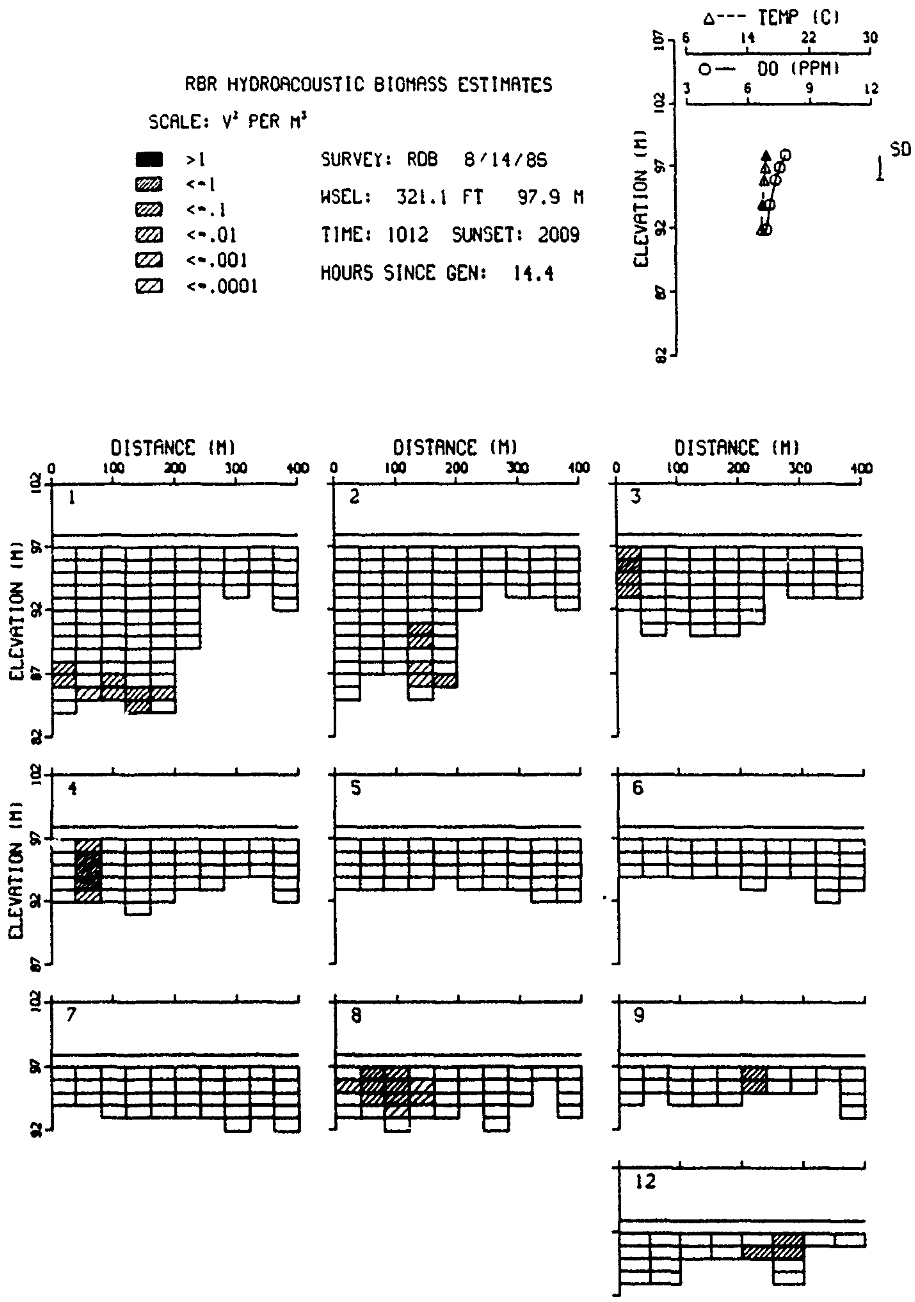


Figure 41. Distribution of relative fish biomass on 14 August 1986 during the day after no generation. (Refer to Figure 28 for explanation of data)